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Technical Report

No. 13509

THE DESIGN, DEVELOPMENT AND FABRICATION OF AN ORGANIC COMPOSITE SHIPPING CONTAINER FOR THE FULL UP POWER PACK (FUPP) (U)

CONTRACT DAAE07-88-C-R049

APRIL 1990

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A container is designed to initially weigh less than half as much as the present metal container. Modifications are required to enable the container to withstand certain testing. Final design reduced weight by 2000 lbs., or 40 percent. While not the 50 percent originally specified, it is a substantial reduction. Depending on the final configuration required for the rail hump test will determine what modifications are required, if any. The container is a combination of composite and aluminum.

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SUMMARY

The transportation of the Full Up Power Pack (FUPP) is difficult because of the large size and weight of the FUPP. Part of this problem is the 5000 pound weight of the container. The container plus the FUPP weighs 14,300 pounds. It was felt that a reduction in weight of the FUPP container of 50% would produce a more manageable shipping unit with accompanying savings in transportation costs.

GDLS has designed, fabricated and successfully tested a composite FUPP container consisting of a two-piece composite outer shell, with an internal aluminum/rubber shock isolation system. The upper cover is a 1" balsa core with .100" thick E-glass/polyester face sheets. The bottom section consists of a .200" thick composite tub into which a dual frame isolation system is mounted.

Initial design of the inner isolation frame utilized pultruded E-glass/polyester channels. During drop testing, there was a joint failure which was traced to excessive flange bending. The inner frame was redesigned out of 6061-T6 aluminum and has successfully passed all tests.

The final design of the composite FUPP container weighed 3000 lbs. or 60% of the current metal unit.

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1.0 INTRODUCTION

The shipping and storage container for the M1 Full Up Power Pack (FUPP) was conceived in 1983. General Dynamics Land Systems Division (GDLS) won a contract and developed a metal container which passed all the required handling tests except for the Rail Hump Test which is still not defined as of this writing.

This heavy container with the FUPP (shown in Figure 1-1) weighed 14,300 pounds. It was too heavy for the standard five ton truck, and required large handling equipment.

Its use in the Forager Exercise in Germany led to a recommendation that the containers weight should be reduced. U.S. Army Tank-Automotive Command (TACOM) issued an Request for Proposal (RFP) for a reduced weight composite container in 1987 which was won by GDLS in 1988. This contract called for design and fabrication of two test containers which would weigh half of the steel container.

2.0 OBJECTIVE

The objective of this contract was to design, fabricate and successfully test a composite FUPP container which weighed approximately one-half of the current metal design. The contract called for fabrication of two containers. Although two were built, one was destroyed during initial impact testing. The other was modified and is currently in government custody.

3.0 CONCLUSIONS

The final design of the lightweight container has reduced its weight by 2,000 lbs. This represents a 40% weight reduction compared to the current steel unit. Areas of the initial design which required redesign were locations on the lower tub which were subject to concentrated loads. These typically required metallic reinforcement to "spread" the load over a greater area of composite. The lower tub is shown in Figure 3-1.

GDLS feels the 2000 lb. weight reduction could be improved by at least 200 lb. through further optimization of the design, but the added cost may not be justified. As it is now, the 40% weight reduction is quite substantial.

As of this writing, the required rail hump test has not been conducted. The government plans to conduct this test after tie down requirements have solidified.

4.0 RECOMMENDATIONS

In construction of any new containers, improvement in performance and/or further reductions in weight could be made by following these recommendations.

4.1 <u>Fork Lift Channels</u>.

Construction of the forklift channel area can be improved. Eliminate the 6 in. steel channels which are used to protect the fiberglass angles from forklift tynes (save 80.625 lbs.). Add a "U" of 3/16 in. aluminum to each of the twelve four-inch angle legs (add 8 lbs.). Increase the length of the angles to replace the six inches of steel channel (add 23.4 lbs.). This results in a net decrease of 49 lbs.

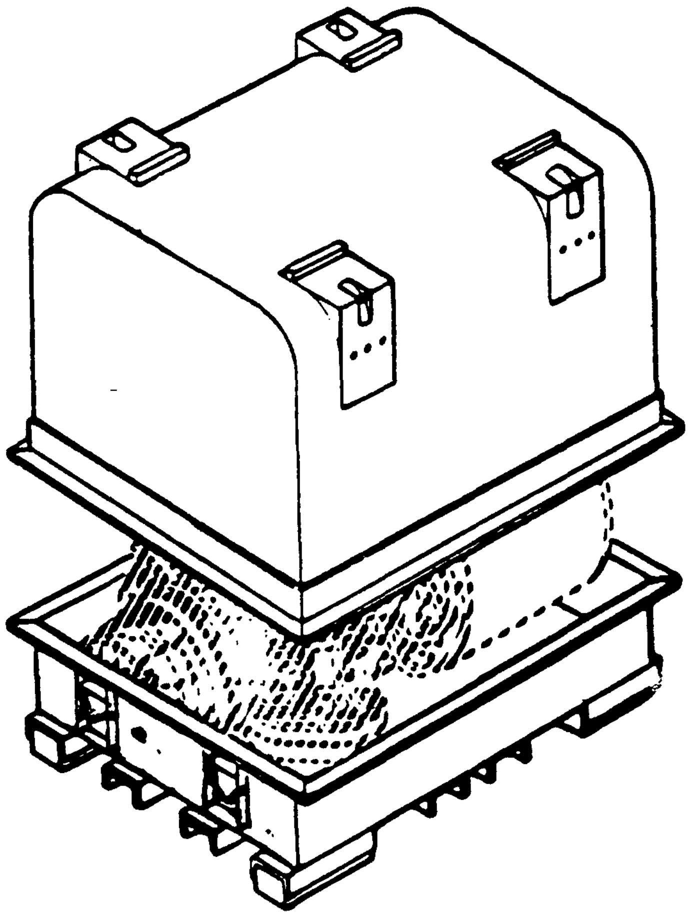


Figure 1-1. FUPP Container - Open

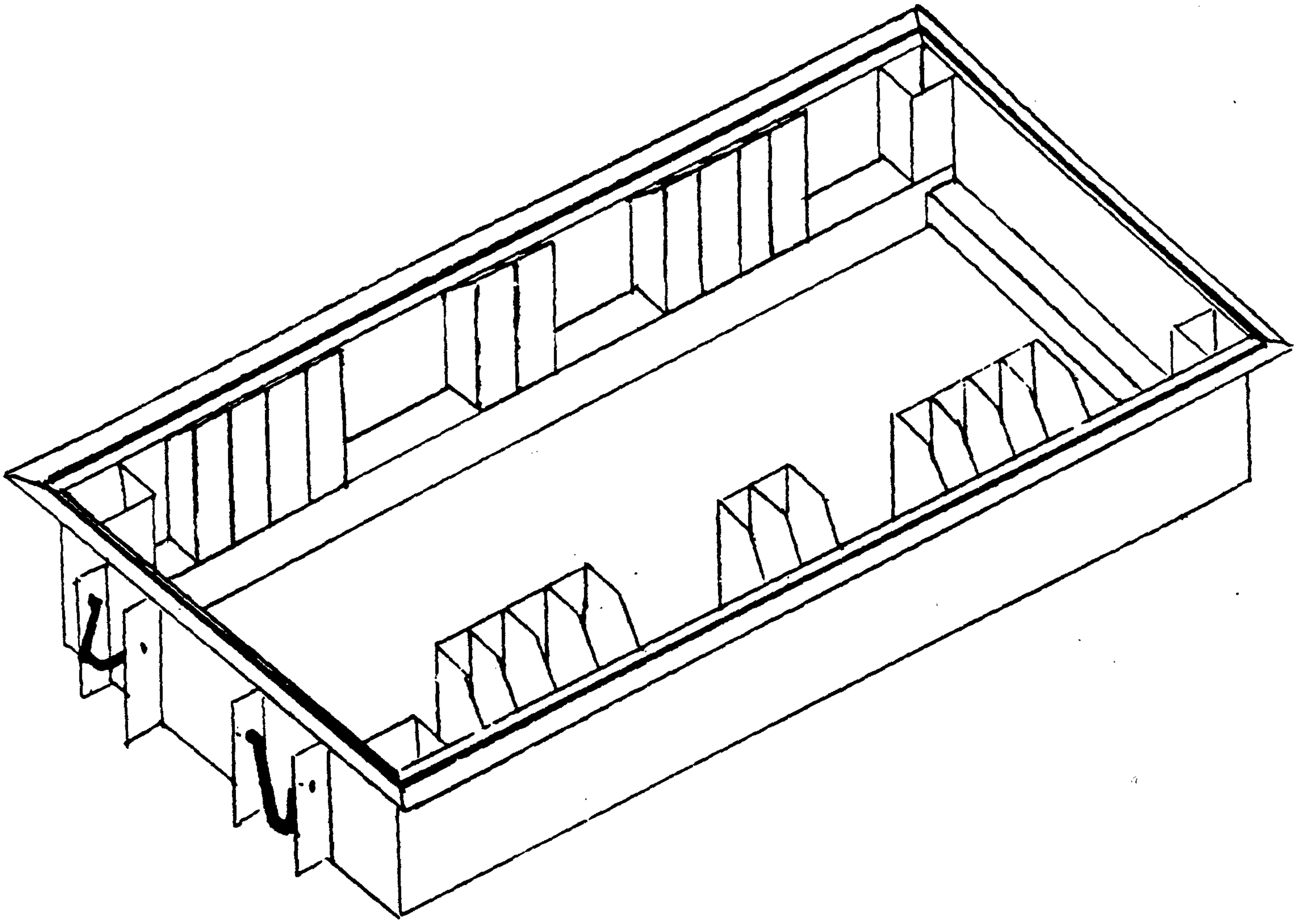


Figure 3-1. Composite Tub With Aluminum Outer Frame

4.2 Change in Floor Reinforcement

Replace the three 3" x 2" x 1/4" alum m angles with a hat section rib (2-3" x 0.20"). The aluminum angles weigh 28 lbs. and the fiberglass ribs weigh 17.5 lbs. - a decrease of 10.5 lbs. Also, thirty-three bolts, nuts, washers, plus the holes through the laminate, will be eliminated for an additional 6 lb. savings. Net savings would be 16.5 lbs.

4.3 Shift in Shear Mount Supports

Viewing the container from the engine end, shift aluminum shear mounts 1.0 in. to the right to adjust for changes due to aluminum vs. composite inner frame. This makes both shear mount supports 7 in.deep. See Figure 4-1.

4.4 Create Deeper Penetration of Forklift Tynes

Cut out 40 in. of a forklift leg to permit further penetration of the long forklift tynes. This will eliminate 5.2 lbs.

Eliminate the 4" x 6" x 1/2" fiberglass angles backing up the skid brackets and strengthening the floor. One angle of 86 in. weighs 28 lbs. Two short angles of 10 in. each weigh 6.5 lbs. The total of 41.0 lbs. is eliminated. This is offset by boxing in the skid brackets with 1/4" steel plate weighing 13 lbs. Net reduction is 28.0 lbs.

4.5 Trowel Out Pliogrip

Trowel out of the pliogrip adhesive to eliminate any gaps resulting from applying the adhesive in rows with a pressure nozzle.

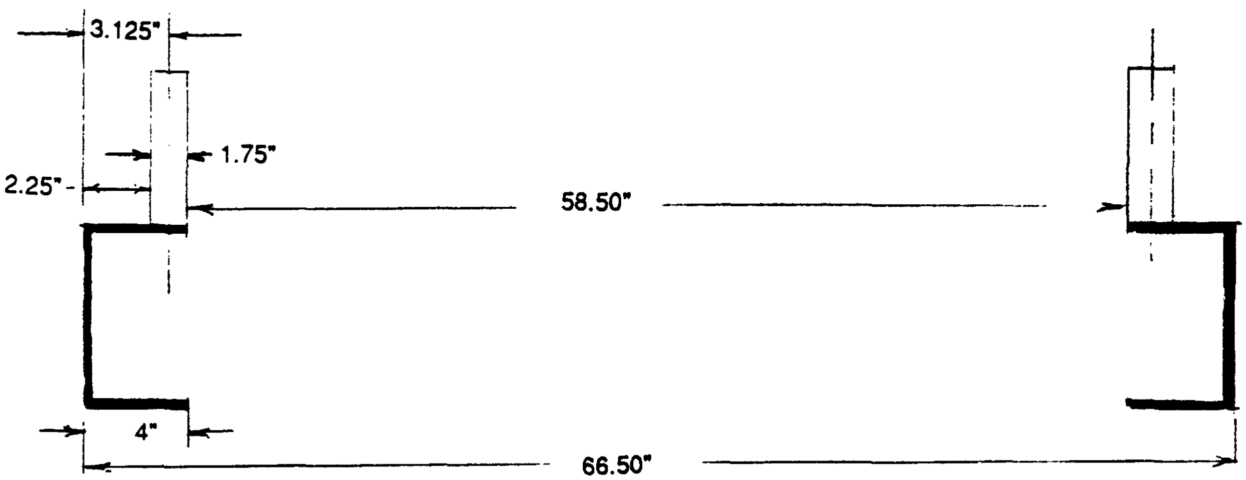
4.6 Change in Gasket

Install a rectangular gasket which sets in a 1/4 in. deep routed channel. Mount the edge within 3/8 in. of the closure bolts. This will cause the gasket to act as a fulcrum with the weight of the container top being balanced by the bolt tension. In addition, by mounting the rectangular gasket in a channel, the gasket will be held in place during closure. See Figure 4-2. This is a performance improvement, no weight savings.

4.7 Tie-Down Changes

Modifications were made to the tie-down angles and their fastening to the framework. This is subject to change when TACOM decides exactly how many tie-down areas they desire on the FUPP container and where they will be located. At present, there are two tie-down areas at each end of the container bottom, roughly one-fourth of the way in from e side of the container. These modifications result in performance improvement but also weight increase as follows:

ALUMINUM INNER FRAME



NOW : 3.125" TO RIGHT WAS: 2.175" TO RIGHT DELTA : 0.950"

∴ REDUCE DEPTH OF LEFT SHEAR MOUNT BY 1" AND INCREASE RIGHT BY 1"

ALUMINUM OUTER FRAME

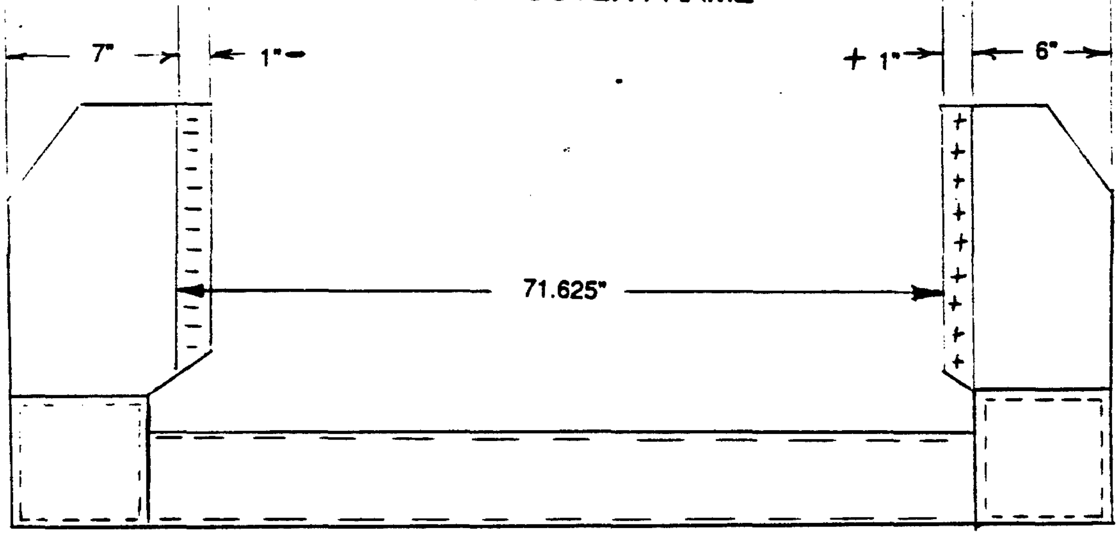


Figure 4-1. Aluminum Inner and Outer Frame

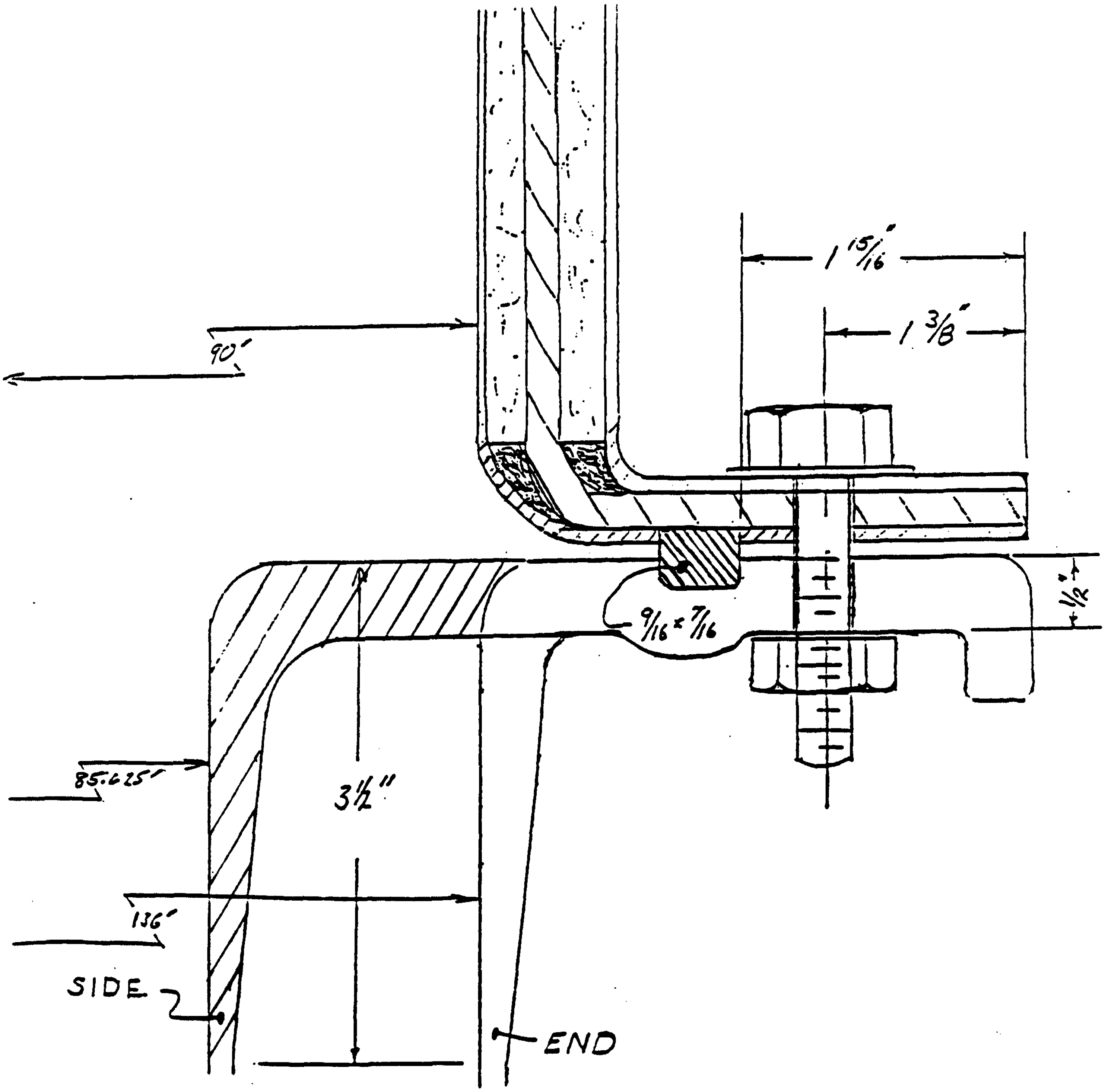


Figure 4-2. Flange Construction

2 -	4" x 4" x 73.6" x .188" square aluminum tubing	44.0 lbs.
8 -	3" x 4" x 4" 1g. x .188" steel angles	11.4 lbs.
2 -	3" x 5" x 68" x .25" aluminum angles	23.8 lbs.
8 -	3" x 6" x .50" aluminum plates	7.2 lbs.
8 -	3" x 6" x .25" aluminum plates	3.6 lbs.
8 -	3/4" bolts & nuts	1.7 lbs.
4 -	3" x .18" x .188" aluminum plates	4.0 lbs.
	Added Weight Total	95.7 lbs.

4.9 Four 2" x 3" x 1/4" x 24" aluminum angles were welded to the 6" x 6" longitudinal tubes over each skid area. This is an addition of 12 lbs. Ten 1/2 in. bolts, five through the 2" x 3" angles and five through the bottom side of the 6" x 6" tubes, secured the skid mounting brackets. Forty nuts and bolts weigh five lbs. The net weight gain is 17 lbs. The strengthening of the skid attachments, plus the material added to withstand assumed tie-down stresses, add a total of 112.7 lbs.

The net increase in weight for this change is 14.0 lbs.

5.0 MATERIALS

All materials used in the lightweight composite container were selected to maximize weight reduction, while minimizing cost impact. As a result of this philospphy, no graphite is used in construction. E-glass is the selected fiber reinforcement due to its high strength and low cost. The Koppers flame retardant polyester resin was selected because of low cost and its room temperature cure characteristics. This was important because a large curing oven was not available for curing the composite. Balsa wood core was used because it provided excellent performance at economical cost. The continuous surface allows easy bonding compared to honeycomb and is much more resistant to water absorption. Long-term exposure to high humidity and temperatures results in approximately 1/2 percent moisture content, about the same as the fiberglass face sheets. Syntactic foam, while technically acceptable, was ruled out because of its high cost. The selected adhesive was Ashland Pliogriop. Reasons included room temperature cure, ease of use, excellent impact resistance, and good gap filling ability. Other materials used were readily available steel, aluminum, and rubber. All materials used are listed in Table 5-1.

5.1 Processing

All processing for the composite FUPP container was done at room temperature. Separate male tools were used to wet-lay-up the upper cover and bottom tub section. Postcure operations, such as mold removal and trimming, were performed using standard shop procedures. All processing took place at Champion Co., in Springfield, Ohio. They subcontracted to provide GDLS the necessary floor space for FUPP container assembly, fabricate internal framework, supply metal reinforcing hardware as needed, and paint and perform testing of the completed unit. Champion was selected to assist GDLS because they currently build the metal FUPP container, were willing to provide shop space for assembly and had access to test facilities. Tooling for the wet-lay-up process was supplied by Wolverine Products, Inc., Roseville, Michigan.

6.0 DESIGN

Table 5-1. **Materials for Lightweight Container**

MATERIAL	DESCRIPTION OR SOURCE
Fiber	CoFab 18 oz/yd stitched E-glass P.C. A1118B, Collins Craft Composites Group, Inc.
Resin	Koppers Dion FR6604T Polyester
Adhesive	Ashland Pliogrip 6600/6620 Urethane
Core	Baltec Contourkore, 9 lb/c.f.
Rubber Shear Mounts	Lord Corp., Industrial Products Division
Steel	High Strength 55ksi min. ten. str.
Aluminum	6061 T4 Heat Treated to T6
Paint	CARC per MIL-C-52039 or MIL-C-46168

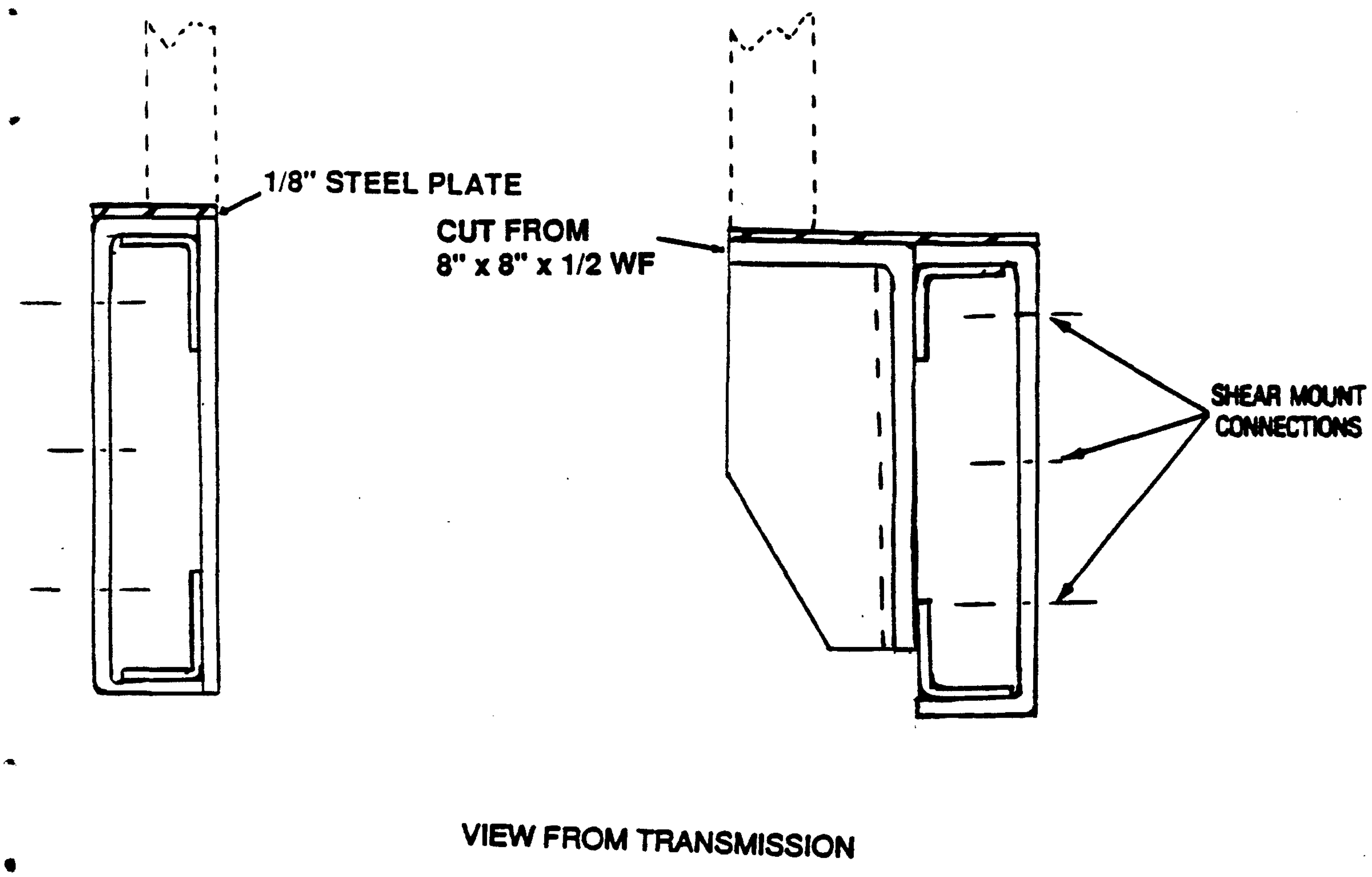
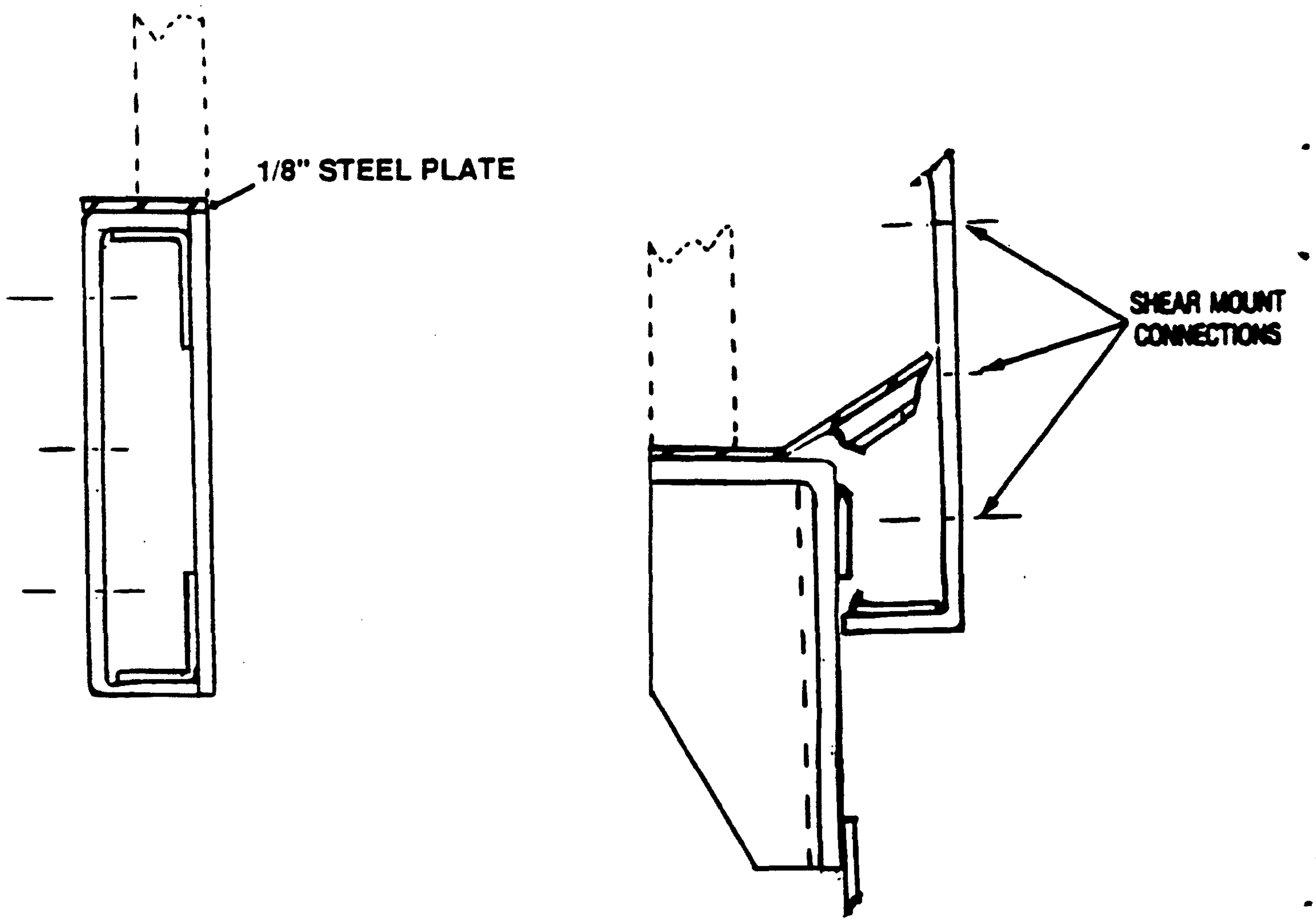


Figure 6-1. Inner Frame Pultruded Joint Design



VIEW FROM TRANSMISSION

Figure 6-2. Inner Frame Pultruded Joint Failure

6.0 DESIGN

6.1 Design Criteria

The FUPP container design criteria is to satisfy the test requirements listed in Table 6-1 while reducing weight by 50%. Also, the FUPP simulator (used in place of actual FUPP) center of gravity was not to experience over 12 g's acceleration in any direction.

6.2 FUPP Inner Support Frame

The inner support frame is suspended by ten rubber shear mounts inside the bottom container structure. This frame accepts the M1 engine/transmission powerpack and must transfer all inertial loads to those mounts.

The initial design utilized pultruded E-glass/polyester and E-glass/vinylester beams. A typical cross section is shown in Figure 6-1. These beams were selected based on their longitudinal bending capabilities being equal to or greater than the steel beams used in the existing metallic container. During drop testing, the inner frame failed. Failure analysis showed the cause to be excessive flange bending at the intersection of the I cross beam and longitudinal channel beam as shown in Figure 6-2. A redesign of this composite joint detail was attempted, but due to the necessary offset or "drop" of the engine crossbeam, it was impossible to achieve a satisfactory web-to-web bolted shear connection (which would have eliminated flange bending). It was, therefore, decided to construct the entire inner frame out of 6061-T6 aluminum. It is shown in Figure 6-3. A welded joint was designed to transfer load without high flange bending. The resulting inner frame was a much cleaner design which survived all testing. The aluminum frame weighed 23 lbs. more than the pultruded composite design, and shifted the FUPP 1.0 inch to the right, but clearances were still adequately maintained. Stress analysis indicates that 4-inch diameter lightening holes could be cut into the beam webs resulting in an 8 lb. reduction, which would bring the net weight increase to 15 lb. over composite.

Table 6-1. Test Conditions

	Test	Description	Notes
1.	Flatwise drop	6"; 12"	Land on hard surface
2.	Edgewise drop	6",12",18",24",30",36",36"	Perform on both ends
3.	Cornerwise drop	6",12",18",24",30",36",36"	Perform on diagonally opposite corners on each end
4.	Horizontal Pendulum	Raised 18" on minimum of 16' radius	Each end (10 ft./sec at impact)
5.	Hoisting	Each ear, singly	Hold for two minutes
6.	Stacking	16' or two containers whichever is greater	192"/74.875" = 2.56 containers. Use two containers
7.	Forklift	Floor strength Overall stability	
8.	Air Tightness	Inflate to 3 psi	No leakage
9.	Trailer Loaded Rail Hump Test	FUPP on trailer, trailer on flat car	Prevent damage through rail movement

6.3 Container Bottom Section

The container bottom section supports the aluminum inner frame and serves as a protective containment vessel for the FUPP. Its design is a hybrid of E-glass/polyester composite skin with

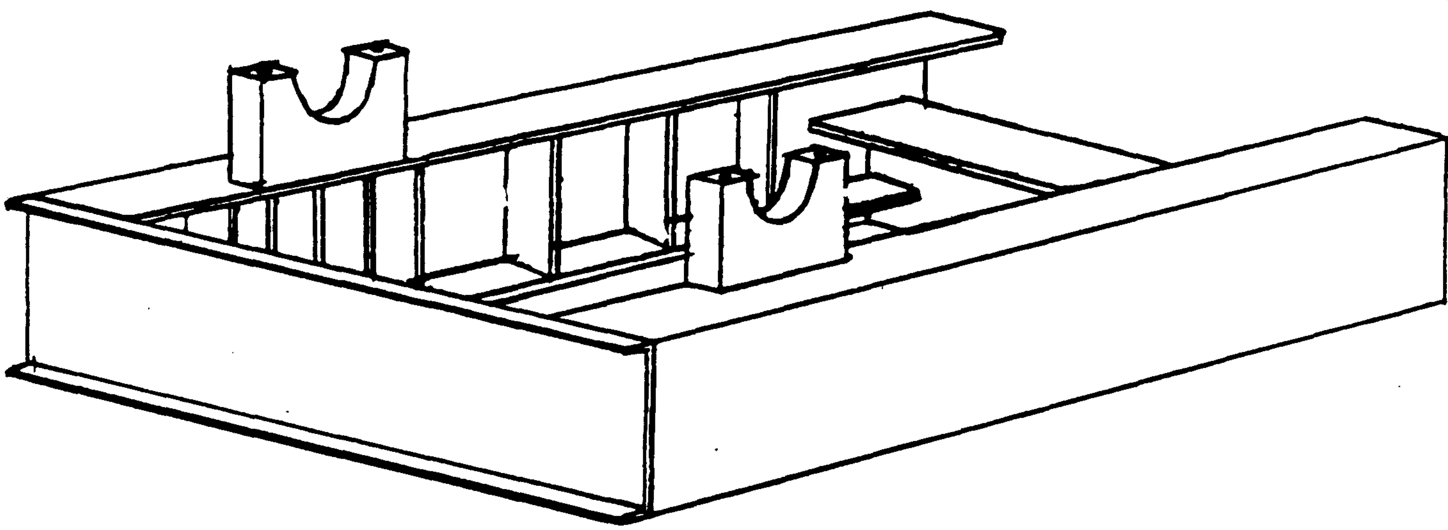


Figure 6-3. Aluminum Inner Frame

6061-T6 stiffeners. Attachment to the inner frame is through the ten rubber shear mounts. Interface with the upper cover is through a horizontal bolted flange which runs the entire perimeter of the container. The floor of the bottom section incorporates skid pads for stacking and impact protection, and forklift guides to aid in lifting. The fore and aft vertical walls feature aluminum tie down brackets with steel rod handles which are used to cable the container during transport. Aluminum tubing is used to reinforce the inner perimeter of the composite tub.

6.3.1 Composite Tub. The basic wall construction is 2/10 in. Cofab glass cloth/flame retardant polyester resin. Inside, radii are kept at 5/8 in. to allow extruded square aluminum tubing to nest as closely as possible to the corners. The horizontal flanges are 1/2 in. thick to allow adequate strength in the bolted joint. This 1/2 in. extends 3.5 in. inches down the vertical wall to form an integral angle stiffener around the perimeter. Initial design of the tub floor had minimal stiffening in an attempt to minimize weight. However, excessive deflections were noted during pressure testing so additional aluminum stiffeners were bolt/bonded to the 2/10 in.composite panel. These were 2" x 3" x 1/4" 6061-T6 extrusions. Test results have proven the validity of this redesign.

6.3.2 Tub Outer Frame. The composite tub is reinforced with 6061-T6 aluminum extrusions and is shown in Figure 6-4. 6" x 6" x 1/4" tubing is used for the longitudinal and vertical corner applications, while 4" x 4" x 3/16" tubing is used on the fore and aft short sides. All metal-to-metal joining is done by welding. The metal reinforcement is joined to the composite with a combination of Pliogrip 2 part urethane adhesive and bolting. The adhesive is strong enough to react all loading and serves as a sealant, but requires bolting to survive during shock testing.

6.3.3 Skid Mounts. The initial design featured skid mounts which were placed in each of the four corners of the bottom. Retainers were made of 1/4 in. thick steel C-channel bonded and bolted to fiberglass skin. One bolt was put through the 6" x 6" tube and 3 bolts were put through the fiberglass skin. Inside the skid brackets a 1-1/2 in. thick piece of Buna rubber was placed on top of the wooden skid blocks. Three half inch bolts held the wooden skid blocks in place. The holes for these bolts through the steel brackets are slots to permit movement (via the Buna rubber pad). To the inside end of the skid brackets a 4" x 6" x 1/2" angle was mounted to prevent shearing of the wood skid blocks along the 1/2 in. retaining bolts. During pendulum impact testing, all four skids sheared off.

The redesign of the skid mount attachment region required adding in a 2" x 3" x 1/4" 6061-T6 aluminum angle to the inside of the composite tub at each of the four corners. This is shown in Figure 6-5. In addition, ten 1/2 in. steel bolts were used at each corner to react the impact load from the skid directly into the tub reinforcement tubes. Pliogrip adhesive was also used at the interface. This attachment minimized loading on the thin (2/10 in.) composite floor. There were no failures in subsequent testing.

6.3.4 Tie-Down Brackets. Four tie-own locations are provided on the composite tub, two in the front and two in the rear. A horizontal 4" x 4" x 3/16" 6061-T6 aluminum tube spans the fore and aft interior wall which serves to back up the point of load introduction. 1/2 in. aluminum angles on the tub exterior are reinforced with 1/4 in. welded aluminum and 3/8 in. bolted (3/4 in. steel bolts) steel doublers. A bent steel rod link is installed in pivot holes, and is held from slipping sideways with cotter pins. This link is free to rotate depending on angle of the applied load. Each tie down location is sized to withstand 40 kips per MIL-STD-209G.

6.3.5 Fork Lift Points. The composite tub bottom surface features 4" x 6" x 1/2" pultruded angles bolted/bonded to the lower surface of the 1/5 in. skin. These were placed to allow fork lift entry from the transmission end and from each side and centered on each side of the center of gravity. They are spaced 28 in. center to center.

CONCERN : EXCESSIVE DEFLECTION OF BOTTOM DURING PRESSURIZATION AND FORK LIFT CONDITIONS

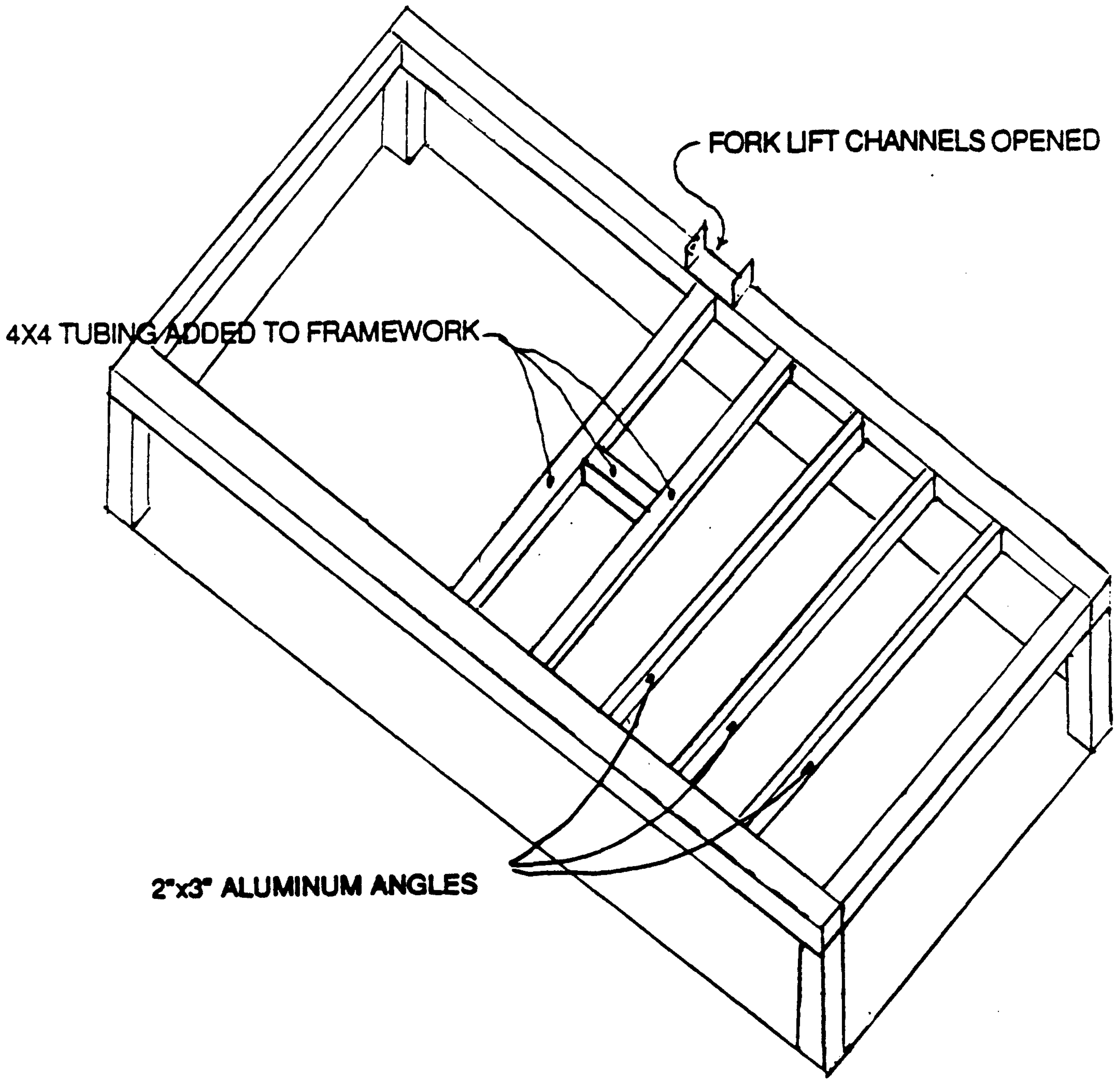


Figure 6-4. Redesign of Bottom Tub

No fork lift entry was provided from the engine end of the tub, because the length of tynes needed to pass the center of gravity point would be too long.

Each end of the fork lift channel initially had a 6 in. length of a 4" x 12" x 1/4" closed section steel tube bonded and bolted to act as a fork guide. This was later modified from a closed tube and an open "c" channel to prevent the bottom of the tube from acting as a fulcrum when attempting to pick up the container using short tynes on the fork lift. Strengthening of the bottom to prevent excessive deflection of the floor from the tips of the fork lift tynes was achieved by welding a 4" x 4" x 3/16" tube on the inside of the tub along the centerline of the fork lift channels between 6" x 6" x 1/4" longitudinal tubes. These two tubes were also interconnected at their centers by a 4 in. cross tube.

6.4 Container Upper Cover

The cover of the container must provide strength to support two loaded containers stacked on top. Light weight must be retained while increasing bending stiffness. Table 6-2 shows comparison of bending stiffness of lightweight material vs. steel.

The upper cover basic construction is a Cofab glass/polyester, balsa core sandwich except for the horizontal attachment flange which is 1/2" solid composite. The basic construction is shown in Figure 6-6. A pultruded 4" x 4" x 1/4" composite angle was embedded in the flange to replace the balsa core as shown in Figure 4-2.

The decision to use balsa core sandwich construction was based on a trade study between several concepts. Deflection, weight, tooling and complexity were considered. Table 6-3 provides the weight vs. deflection data for both sandwich and sandwich/rib construction. GDLS believes the 1 in. sandwich is the optimal selection based on cost and performance.

6.4.1 Lifting and Stacking Points. An important consideration in the top design is the incorporation of structural hard points for accommodating the lifting provisions. Figure 6-7 illustrates the GDLS concept for this area. Composite lifting provisions were discarded in favor of a steel concept, especially when severity of the single eye lift condition was considered. This steel lift eye is held in place by Pliogrip adhesive and a row of six 1/2" shoulder bolts in each of it's legs.

The lifting locations also serve as stacking hardpoints. The requirement for stacking is two loaded containers (24507 lbs.) on top of a third container. Local reinforcement consists of bolting/bonding 39" x 15" x 1/2" E-glass/polyester plates to the inside of the container at four locations, backing up each lift eye. The purpose is to distribute the concentrated vertical load more evenly into the wall structure.

6.4.2 Leakage. The large number of bolts penetrating through the skin of the container represents an area for potential leakage, especially leakage during the pressure test. Special provisions against leakage were taken using rubber washers and silicone sealing compound. Leakage of a weeping nature through the hand-layed-up fiberglass laminate was extremely low and was easily stopped upon painting. All leaks were sealed. The one area which needed to be carefully handled was the closing of the container on the 9/16 in. round gasket. This has been described in section 4.7, "Recommendations."

7.0 STRESS ANALYSIS

The FUPP container has been analyzed using conventional and finite element methods. Margins of Safety for the final design are presented in Table 7-1. A 1.5 Factor of Safety was used per AMCP-706-357.

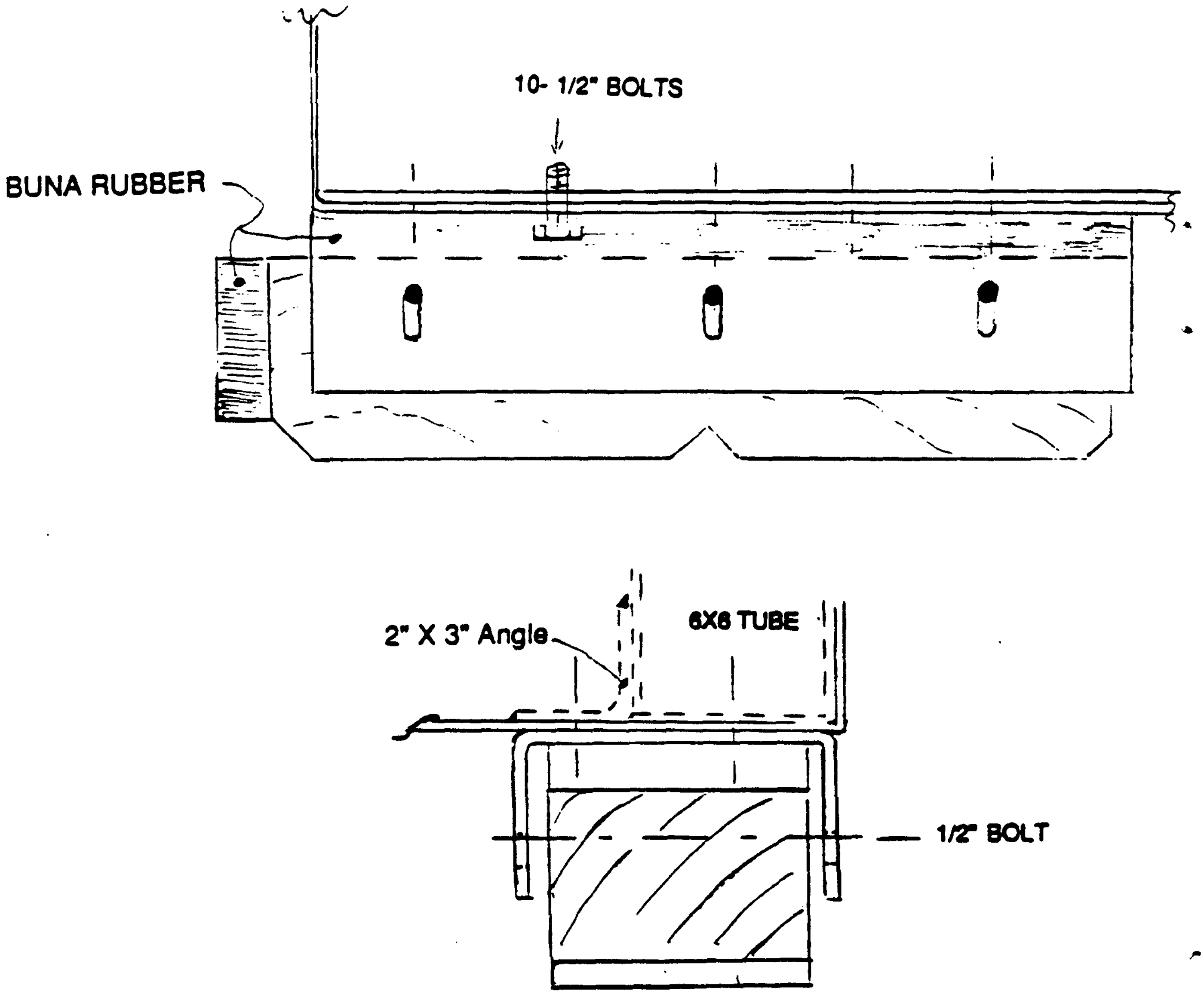


Figure 6-5. Skid Mount

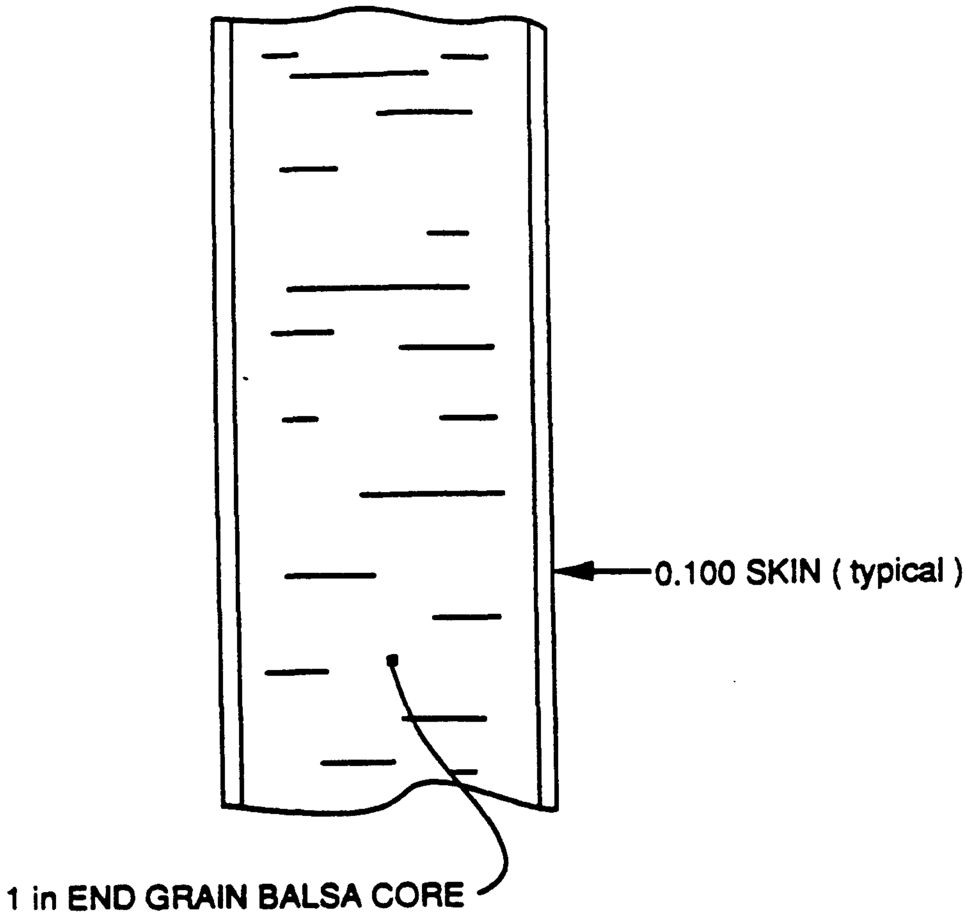
Table 6-2. Sandwich Construction Enhances Stiffness

MATERIAL	WALL CONFIGURATION	MOMENT OF INERTIA -in^4	BENDING STIFFNESS -lb in^2	COMPARATIVE STIFFNESS
STEEL	.0747 in	0.000035	1015	1.00
E-GLASS FABRIC	.200 in	0.000667	1667	1.64
E-GLASS SPRAY-UP	.200 in	0.000667	1000	0.98
GRAPHITE	.200 in	0.000667	8004	7.88
E-GLASS SANDWICH	.1 / 1. / .1	0.060667	182000	179

Table 6-3. Material Thickness / Number of Stiffners vs. Weight

CONSTRUCTION	NUMBER OF STIFFENERS	MAXIMUM OF DEFLECTION, IN.	MAXIMUM STRESS, PSI	CONTAINER TOP WEIGHT
.1/.5/.1 *	NONE	13.45	52400	443
.1/.5/.1	ONE	3.85	25985	471
.1/.5/.1	THREE	2.00	9750	527
.1/1./.1	NONE	4.06	28750	499
.1/1./.1	ONE	1.80	15800	527
.1/1./.1	THREE	1.40	12105	583

*Laminate configuration thicknesses are given as face/core/face (i.e. .1/.5/.1 represents a laminate with two 0.1 inch face sheets with a .5 inch core).



SKIN :

ISOPTHALIC FLAME RETARDANT POLYESTER RESIN USED TO HAND LAY UP FIVE LAYERS OF 18 oz E GLASS KNITTED CLOTH IN A 0-90° PATTERN TO A THICKNESS OF 0.100 INCHES,FIBER VOLUME OF 30 %.

Figure 6-6. Basic Construction of Upper Cover

7.1 Inner Frame

The engine cross beam is critical in bending due to the concentrated 38,700 lb. ultimate load applied at 44% span. The resulting Margin of Safety is + .80. Loading on the inner frame is as shown in Figure 7-1. Analysis is presented in Figure 7-2.

7.2 Bottom Tub

The bottom tub is subject to drop and pendulum impact testing, the most severe condition being pendulum impact. The critical region for this condition is the skid mount attachment. This area was beefed up after failure of the initial concept. All Margins of Safety are now positive. Stress analysis is presented in Figure 7-3.

7.3 Upper Cover

This composite upper cover is designed to prevent excessive deflections during pressurization. As a result, stresses tend to be low except for hoist areas, which are steel reinforced. Analysis was performed using the NISA finite element code. Stress contour plots for laminate and reinforcement regions are shown in Figures 7-4 and 7-5.

8.0 TESTING

The lightweight fiberglass-aluminum container has passed all tests except the trailer loaded rail hump test. The rail hump test has not yet been defined by the Army.

A report on testing and test conditions is made a part of this final report. See Appendix A.

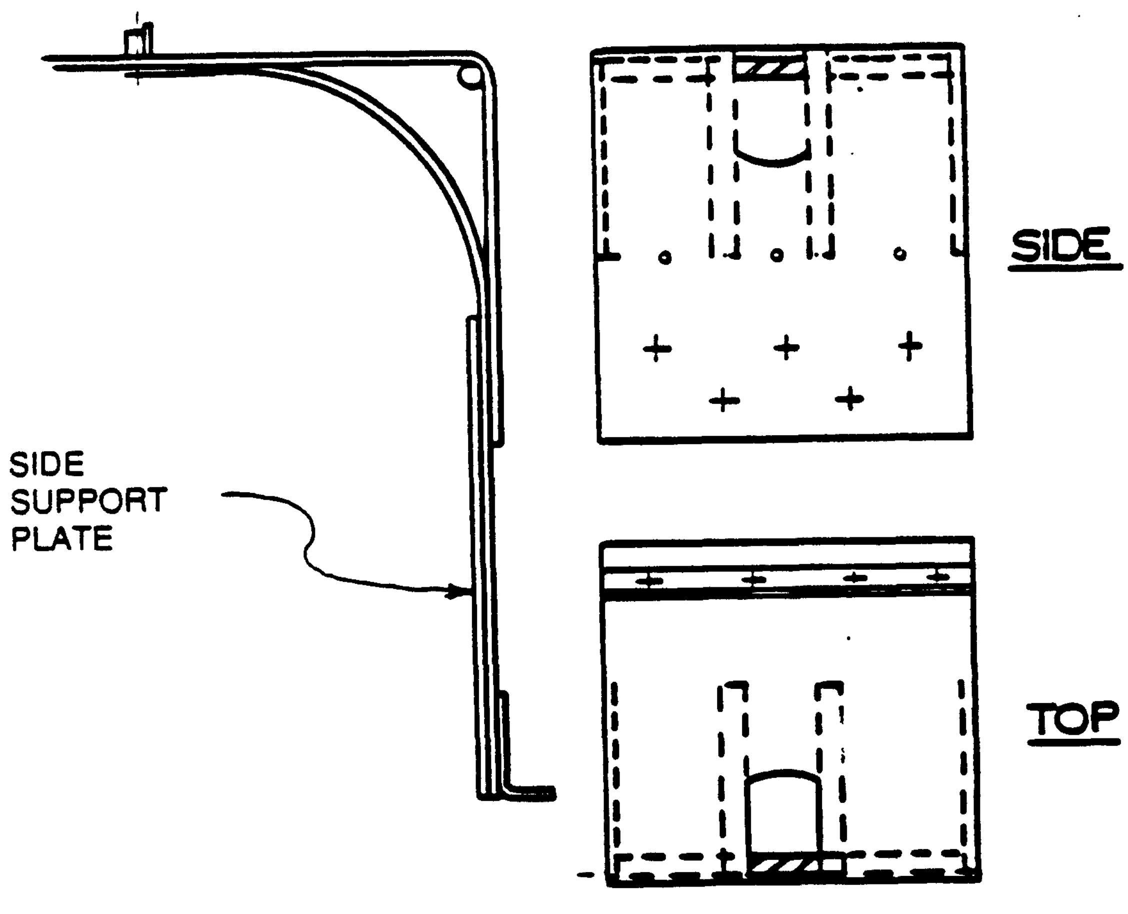


Figure 6-7. Lifting Eye and Side Support Plate

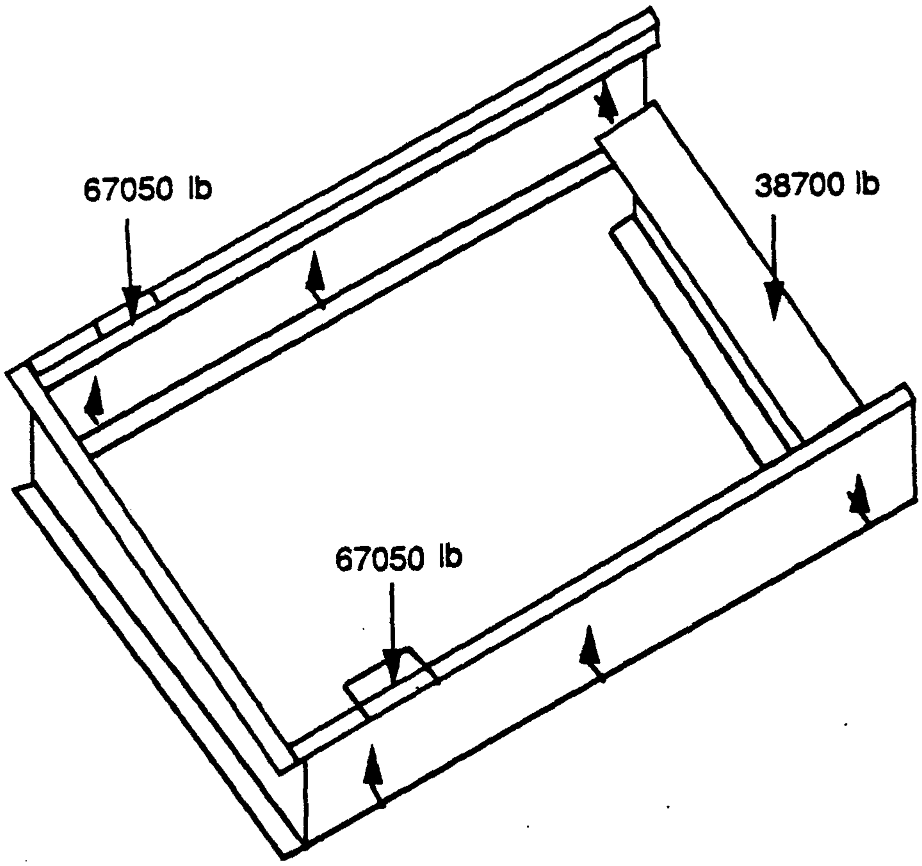
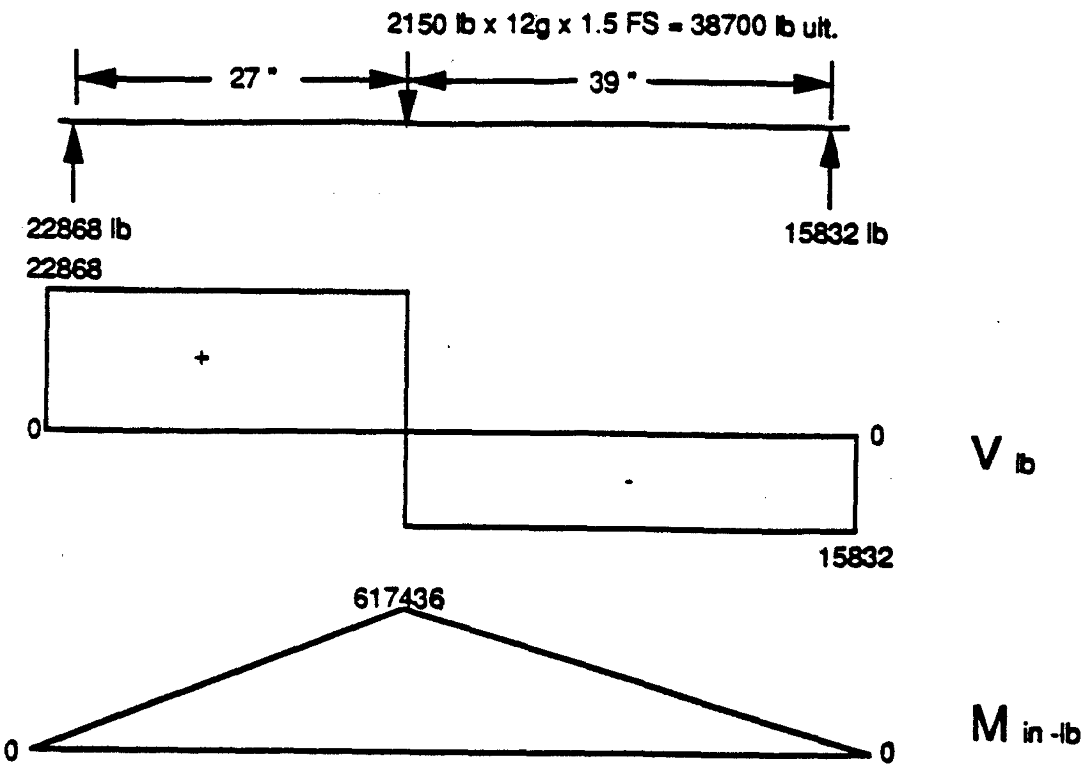


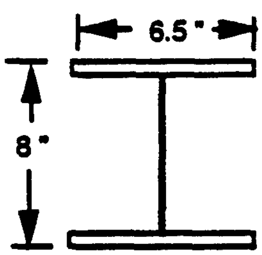
Figure 7-1. Inner Frame Ultimate Loads

Table 7-1. FUPP Container Margin of Safety Analysis

COMPONENT	DETAIL	CONDITION	MODE	MARGIN OF SAFETY
INNER FRAME	ENGINE CROSS BEAM	VERTICAL DROP	BENDING	+ 0.36
BOTTOM TUB	SKID PAD	PENDULUM IMPACT	BOLT BEARING	+ 0.06
UPPER COVER	HOIST PLATE	HOISTING	TENSION	+ 0.55



BENDING CHECK :



6.5 x 8 x 8.32 6061-T6 BEAM

$I = 84.15\ in^4$ PER ALCOA HDBK

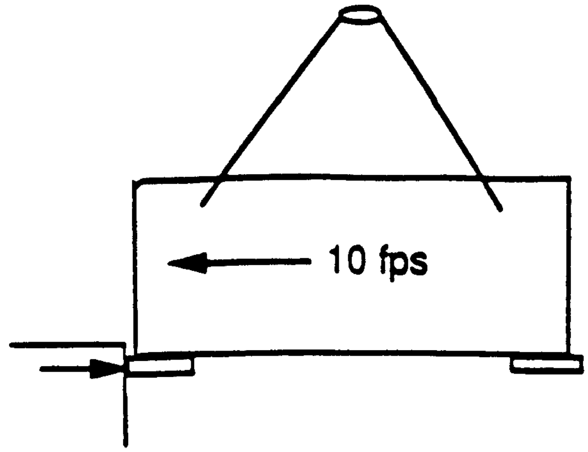
$$\frac{Mc}{I} = \frac{617436 \times 4}{84.15} = 29.3\ ksi$$

$F_{tu} = 40\ ksi$

$$\text{MARGIN OF SAFETY} = \frac{40}{29.3} - 1 = +.36$$

Figure 7-2. Inner Frame Cross Beam Stress Analysis

CONDITION:



PENDULUM
IMPACT

LOAD CALCULATION:

$S = 1/2\ AT$ ASSUME S= .25 in (movement of C.G. at impact)

$V = AT$ V = 10 fps

$S = \frac{V^2}{2A}$ A TO DECELERATE = $\frac{10^2}{2 \times .25}$ = 200 ft/s^2

$A = \frac{V^2}{2S}$ 200 ft/s^2 = 6.2 g (limit)

FACTOR OF SAFETY = 1.5 per AMCP - 706 -357

6.2 g x 1.5 = 9.3 g (ultimate) ASSUME ONE CORNER REACTS 90% OF LOAD

BOLT CHECK: FUPP + CONTAINER = 12,600 lbs

12.600 x 9.3 x 0.9 = 105462 lb (ult) or 10.5 kips for each of 10 bolts, grade 5.

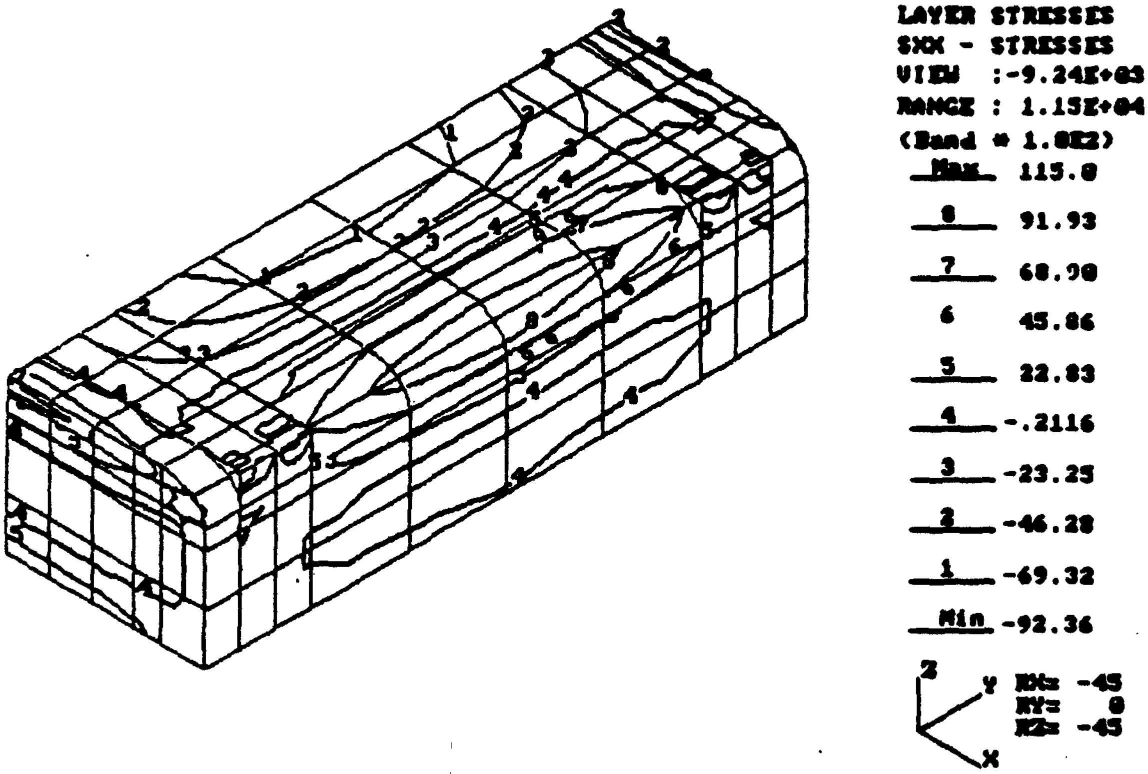
BEARING STRESS = $\frac{P}{DT} = \frac{10.5}{.5 \times .25}$ = 84 kips

6061 T6 FBRU = 89 ksi "B" SINGLE SHEAR STRENGTH = 14.1 kips

BEARING M.S. = $\frac{89}{84} - 1 = + .06$ * SHEAR M.S. = $\frac{14.1}{10.5} - 1 = + .34$ *

* FACTOR OF SAFETY = 1.5

Figure 7-3. Skid Mount Stress Analysis



MAXIMUM STRESS : 11,500 psi (Limit)

STRESS ALLOWABLE : 30,000 psi

$$\text{MARGIN OF SAFETY} = \frac{30{,}000}{11{,}500 \times 1.5} - 1 = +.74^{*}$$

*FACTOR OF SAFETY = 1.5

Figure 7-4. Top Cover Maximum Laminate Stresses

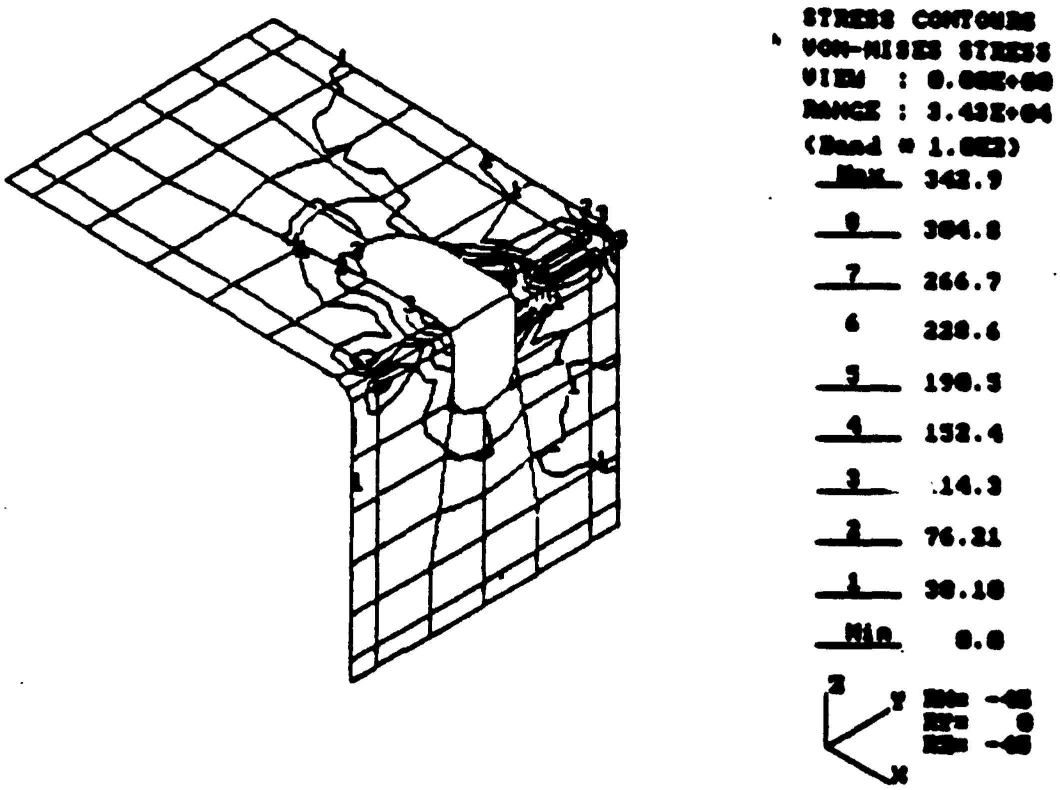


PLATE: 5/16 in 4130 STEEL
F_u = 80 ksi
MAX PLATE STRESS = 34.3 ksi (limit)

$$\text{MARGIN OF SAFETY} = \frac{80}{34.3 \times 1.5} = +.55\,*$$

ROD: 1.5 in DIA. HIGH STRENGTH STEEL
F_u = 60 ksi
MAX ROD STRESS = 24.5 ksi

$$\text{MARGIN OF SAFETY} = \frac{60}{24.5 \times 1.5} = +.63\,*$$

* FACTOR OF SAFETY = 1.5

Figure 7-5. Top Cover Hoist Area Stress Contours

APPENDIX A

TEST REPORT FROM CHAMPION

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MEMORANDUM TEST REPORT
NO. 326 FOR
GENERAL DYNAMICS LAND SYSTEMS
WARREN, MICHIGAN
FULL UP POWERPACK CONTAINER
CHAMPION P/N 00166000000

SUBMITTED BY
THE CHAMPION COMPANY
400 HARRISON STREET
SPRINGFIELD, OHIO 45505

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CHAMPION
Established 1979

THE CHAMPION COMPANY
Special Products Division

19,February,1990

General Dynamics
Land Systems Division
P.O. Box 2071
Warren, Michigan 48090

SUBJECT: Memorandum Test Report No. 326

Gentlemen:

We submit the following as a letter report of the tests performed on two separate occasssions per TACOM specification S.O.P. No. 7 as ammended by the GDLS STATEMENT OF WORK.

PURPOSE:

To report the data and observations when the composite Full Up PowerPack container is subjected to the tests specified in TACOM specification S.O.P. No. 7 as ammended by the GDLS Statement of Work.

FACTUAL DATA:

The subject container is made of various composite materials, ferrous and non-ferrous metals. It is rectangular in shape and split at the closure flange into unequal top and bottom sections. The container is supported on four (4) hardwood skids and has provisions for forklift entry from both sides and the aft end. The container also has hoisting provisions as part of the stacking brackets on the top section.

The overall dimensions of the container:
Length: 148.250 inches approx.
Width : 97.875 inches approx.
Height: 74.875 inches approx.

The exterior volume of the container is 628.72 cubic feet.
The empty or tare weight of the container is 3000 pounds.
The gross weight of the container is 12260 pounds.

The container was loaded with a 9260 lbs. dummy load during all testing.

Dates of testing: 19,December,1989 and 24,January,1990

400 Harrison Street P.O. Box 967
Springfield, Ohio 45501-0967
Telephone 513-324-5681 FAX 513-324-2397

1 MISCELLANEOUS TESTING:

1.1 AIR TIGHTNESS TEST
The assembled container less the dummy load was shipped to GDLS so that they could perform the Air Tightness Tests. See appendix "A" for the procedure GDLS used and the results.

2 TESTING PERFORMED ON 19,DECEMBER,1989

2.1 INSTRUMENTS:

2.1.1 Accelerometers: STATHAM,Strain Guage Type, Model No. A5A-25-350, serial no. 14079, 14483A, and 14567, all calibrated 23, February, 1984 to N.B.S.

2.1.2 Amplifier: BRUSH ELECTRONICS, 6 KC Carrier Amplifier System, Model No. 13-5443-00, serial no. 109 and 147, calibrated 24, February, 1985 and 10, April, 1984 to N.B.S.

2.1.3 Recorder: Graphtec Thermal Arraycorder, Model No. WR7600, Leaseametric Inc. asset no. 01350404 and traceable through N.B.S.

2.2 PREPARATION FOR TESTING:
The instrumentation was located on the dummy load as near as possible to the center of gravity of the suspended mass in the vertical, longitudinal, and transverse positions and balanced prior to testing.

2.3 FLATWISE DROP TEST (S.O.P. No. 7, paragraph 5.15.11)-Series #1
(See paragraph 2.11 of this report)

	#1 (Vertical)	#2 (Transverse)	#3 (Longitudinal)
6"	0.0	2.5	0.9
12"	0.8	3.2	0.5

2.4 EDGEWISE DROP TEST (S.O.P..No. 7, paragraph 5.15.11)
(See paragraph 2.11 of this report)

2.4.1 Forward End-Series #1

	#1 (Vertical)	#2 (Transverse)	#3 (Longitudinal)
6"	0.1	0.8	1.5
12"	0.1	1.8	1.7
18"	0.0	2.7	2.0
24"	0.0	2.9	2.5
30"	0.0	5.0	8.0
36" No.1	0.0	3.5	2.8
36" No.2	0.0	4.6	6.0

(2.4 cont'd)

2.4.2 AFT END-Series #1

	#1 (Vertical)	#2 (Transverse)	#3 (Longitudinal)
6"	0.0	2.5	2.6
12"	0.0	3.6	3.1
18"	0.0	4.5	3.8
24"	0.0	6.1	5.0
30"	0.0	5.8	4.8
36" No.1	0.0	6.0	4.8
36" No.2	0.0	6.0	5.1

2.5 CORNERWISE DROP TEST (S.O.P. No. 7, paragraph 5.15.8)
(See paragraph 2.11 of this report)

2.5.1 Forward End-Series #1

	#1 (Vertical)	#2 (Transverse)	#3 (Longitudinal)
6"	0.0	1.5	1.9
12"	1.1	1.9	2.6
18"	1.5	2.7	2.3
24"	1.2	3.6	5.2
30"	1.6	3.8	3.9
36" No.1	1.9	3.6	5.6
36" No.2	1.8	4.2	5.8

2.5.2 AFT END-Series #1

	#1 (Transverse)	#2 (Vertical)	#3 (Longitudinal)
6"	0.1	0.8	1.5
12"	0.1	1.8	1.7
18"	0.0	2.7	2.0
24"	0.0	2.9	2.5
30"	0.0	5.0	8.0
36" No.1	0.0	3.5	2.8
36" No.2	0.0	4.6	6.0

2.6 EDGEWISE DROP TEST (S.O.P. No. 7, paragraph 5.15.11)
(See paragraph 2.11 of this report)

2.6.1 Forward End-Series #2

	#1 (Transverse)	#2 (Vertical))	#3 (Longitudinal)
24"	0.0	3.1	3.0
36"	0.0	3.2	1.5

2.11 SUMMARY OF TESTING PERFORMED ON 19, DECEMBER, 1989:

2.11.1 Upon completing the tests described in 1.3, 1.4.1, 1.4.2, and 1.5.1 it had become apparent that there was confusion as to which accelerometer was in the vertical position. It was also quite apparent that vertical accelerometer was not functioning properly. The container and equipment were taken inside so that The Champion Company could inspect the equipment for damage and/or to pin point the malfunction. Once inside the equipment performed properly so again the container and equipment were taken back out to the test site. Two preliminary flat drops were performed and it was found that the vertical accelerometer was again not operating properly. This situation was discussed by all present and it was decided that the vertical accelerometer was being affected by the adverse weather conditions we were experiencing. It was also decided that since the transverse accelerometer did not appear to be affected as much, that we would switch the transverse and vertical accelerometers so that we would record the vertical and longitudinal accelerations only.

2.11.2 After the above situation was corrected it was decided that rather than repeating all the tests that we would proceed on with the tests in 2.5.2 and 2.9 that had not already been performed and then repeat the tests in 2.6.1, 2.6.2, 2.7.1, and 2.8.

2.11.3 Prior to performing the tests specified in 2.9 it was observed that the skid brackets were coming free from the bottom section of the container. It was the decided that we would proceed with the pendulum impact tests in 2.9. During these tests the skid brackets were totally broken away from the bottom section of the container.

2.11.4 While performing the tests in 2.10, it was observed that while lowering the loaded container, back to its' base, that the bottom section was being damaged. It was decided that rather than damaging the container any further that we would abort the testing so that a minimum of modifications could be performed on the container and enable the container to be retested at later date.

3 The container was opened and the dummy load removed for the purpose of modifying the deficencies. These modifications were incorporated under the direction and supervision of GDLS.

(2.6 cont'd)

2.6.2 AFT END-Series #2

	#1 (Transverse)	#2 (Vertical)	#3 (Longitudinal)
24"	0.0	3.2	1.6
36"	0.0	4.6	1.8

2.7 CORNERWISE DROP TEST (S.O.P. No. 7, paragraph 5.15.8)
(See paragraph 2.11 of this report)

2.7.1 Forward End-Series #2

	#1 (Transverse)	#2 (Vertical)	#3 (Longitudinal)
24"	0.0	4.2	3.2
36"	0.0	4.8	2.6

2.8 FLATWISE DROP TEST (S.O.P. No. 7, paragraph 5.15.11)-Series #2
(See paragraph 2.11 of this report)

	#1 (Transverse)	#2 (Vertical)	#3 (Longitudinal)
12"	0.0	6.2	2.0

2.9 PENDULUM IMPACT TEST (S.O.P. No. 7, paragraph 5.15.12)

	#1 (Transverse)	#2 (Vertical)	#3 (Longitudinal)
Aft End	0.0	1.6	5.9
Forward End	0.0	0.9	4.5

2.10 HOISTING TEST (S.O.P. No. 7, paragraph 5.15.14)
(See paragraph 2.11 of this report)

The loaded container was lifted free of the ground by only two (2) of its' four (4) hoisting ears, due to difficulties encountered on the pendulum impact test.

No deformation at the hoisting brackets was observed.

4 TESTING PE RMED ON 24,JANUARY,1990

4.1 INSTR MENTS:

4.1.1 Accelerometers: BRUEL & KJAER Piezoelectric Triaxial Accelerometer, Model No. 4321, Leasametric Inc. asset no. 01335421 and traceable through N.B.S.

4.1.2 Amplifier: BRUEL & KJEAR Charge Amplifiers, Model No. 2635, Leasametric Inc. asset no.'s 01396746, 01399658, and 1155976 and traceable through N.B.S.

4.1.3 Recorder: Graphtec Thermal Arraycorder, Model No. WR7600, Leaseametric Inc. asset no. 01350404 and traceable through N.B.S.

4.2 PREPARATION FOR TESTING:

The instrumentation was located on the dummy load as near as possible to the center of gravity of the suspended mass in the vertical, longitudinal, and transverse positions and balanced prior to testing.

4.3 PENDULUM IMPACT TEST (S.O.P. No. 7, paragraph 5.15.12)

	#1 (Longitudinal)	#2 (Vertical)	#3 (Transverse)
Aft End	11.6	5.2	7.6
Forward End	11.9	8.8	10.6

4.4 CORNERWISE DROP TEST (S.O.P. No. 7, paragraph 5.15.8)

4.4.1 Forward End-Series

	#1 (Longitudinal)	#2 (Vertical)	#3 (Transverse)
24"	4.2	6.1	6.5
36"	4.8	5.8	5.6

4.4.2 AFT END

	#1 (Longitudinal)	#2 (Vertical)	#3 (Transverse)
24"	8.6	4.9	6.4
36"	9.5	8.4	11.9

4.5 CONCENTRATED LOAD RESISTANCE(S.O.P. No. 7,paragraph 5.15.13.1)

The container has a height of 74.875, the specification states that a weight of two like loaded containers or the number of like loaded containers that can be stacket to a height of 16 FT. (192") whichever is greater: therefore 192.00/74.875 or 2.56 additional like loaded containers. Based on this calculation the greater of the two is two (2) like loaded containers.

Weight needed for the test = 2 x 12260 lbs. minimum applied load. An actual weight of 24506.6 lbs. was applied to simulate the stacking of the containers.

No deformation was observed.

4.6 FORKLIFTING TEST (S.O.P. No. 7, paragraph 5.15.16)

The loaded container was lifted free of the ground by means of the fork lift and transported a minimum of 100 ft. utilizing the side entry fork pockets and then the aft end entry.

The container demonstrated good stability while it was being transported.

5 AIR TIGHTNESS TEST (S.O.P. No. 7, paragraph 5.15.6)

After testing, the container was closed, with the engine installed, and the breather valves were removed or blocked off. An air line connection with an air pressure guage was installed at the access port and air was introduced to the container at a slow rate. Periodically the air was shut off in order to read the internal pressure of the container. Due to deformation observed during the introduction of air the air line was closed and a reading of 2.8 PSIG was all that was obtained.

Numerous leaks were found at the gasket cavity and other various locations on the container. Numerous attempts were made to seal the leakage but were unsuccessful.

6 MISCELLANEOUS:

Pictures are enclosed to aid in visualizing the tests performed on the dates of 19, December, 1989 and 24, January, 1990.
The recorded tapes of the tests that were performed were not able to be reproduced, The Champion Company will keep the originals on file at our facility.

PERSONNEL WITNESSING THE TEST:

Philip Bartling,	The Champion Company;	Mgr of Engineering Services
Gerald Burt Jr.,	The Champion Company;	Asst. Mgr. of Engineering
Ronald Salyers,	The Champion Company;	Drafter/CNC Programmer
Robert Parrett,	The Champion Company;	Drafter
Steve Jennings,	The Champion Company;	Contract Administrator
Mike Brown,	TACOM;	Packaging Branch
Donald Osterberg,	TACOM AMSTA-TMF	
Carl Luther,	GDLS	

REPORT SUBMITTED BY:

THE CHAMPION COMPANY

Gerald R. Burt Jr.
Assistant Manager of Engineering

APPENDIX B

LEAKAGE TEST REPORT

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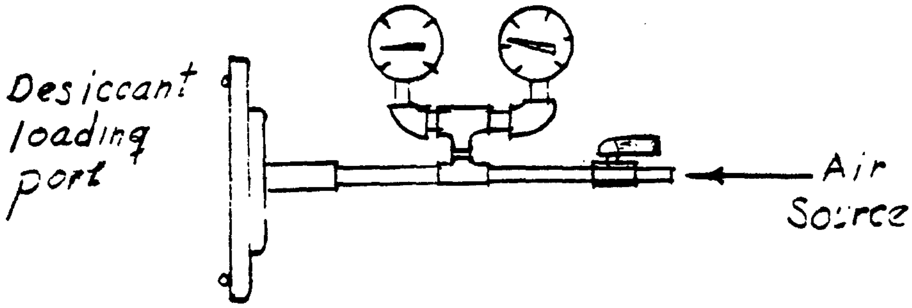
AIR LEAKAGE, FUPP CONTAINER

Objective

To check the FUPP container for leakage of air and to correct the leaks.

Method:

Both the pressure limit valves were removed from the container and replaced with gasketed metal disks. An air feed tube was assembled to provide: 1) a means of inputting compressed air, 2) a means to shut off the air, and 3) gauges to check actual pressure. This feed tube was attached to the desiccant loading port.



Two gauges were used in order to verify the accuracy of the pressure. One gauge read 0-3 psi and the second gauge read 0-5 psi.

Pressure has to be admitted slowly to prevent the gauges from being effected by the rush of high pressure air.

Procedure:

With the inlet valve closed, hook up the compressed air line via a quick couple connector. Slowly open the inlet valve and allow pressure to build up in the FUPP. Level off at 1 psi and close the input valve. Check the gauges to determine whether pressure is being held. Determine by time vs. drop if the leakage is major or minor. If the contaniner is leaking, open the air input valve to replace lost air and shut it down sufficient to maintain pressure at 1 psi.

Using soapy water and brush, first determine whether the gasket 'o' ring is properly seated. This is the most probable place for leaks to occur.

Next, check the various bolts going through the bottom of the container and the sides of the bottom. Then, check the lifting eye retaining bolts. Last, check the fiberglass laminate itself to check for leakage.

Repair leaks in the bolt areas by using rubber washers and silicone caulking compound. Leaks through the fiberglass laminate can be sealed by applying a coating of resin.

AIR LEAKAGE, FUPP CONTAINER (Conti d)

Results:

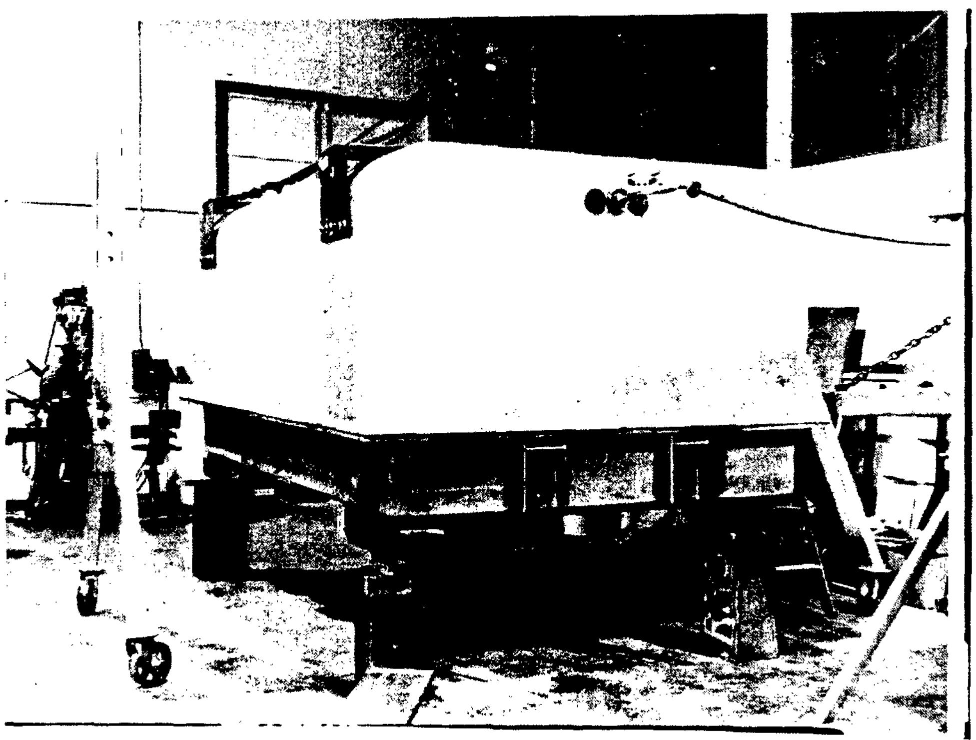
The procedure outlined under procedures was followed successfully. The bottom of the container had several bolts with minor leaks. Although the inside surface was against the contruction mold, several areas appeared to be resin starved. The entire inner surface of the bottom was painted with resin.

Major leaks were located in the shoulder bolt areas of the lifting eyes. These bolts washers were covered RTV on the inside of the cover. Secondly, the bolts were removed from the outside and RTV applied along the bolt, on the washers, and bolt head.

A few minor leaks were found in the laminate itself. More importantly the bolt down flange area had serious leaks where the flange intersected the verticle sides. All these leaks had resin brushed on in a heavy coating.

Pressure for all of these tests was at 1 psi.

Total leakage was 0.1 psi in 30 minutes.



APPENDIX C

TEST PICTURES

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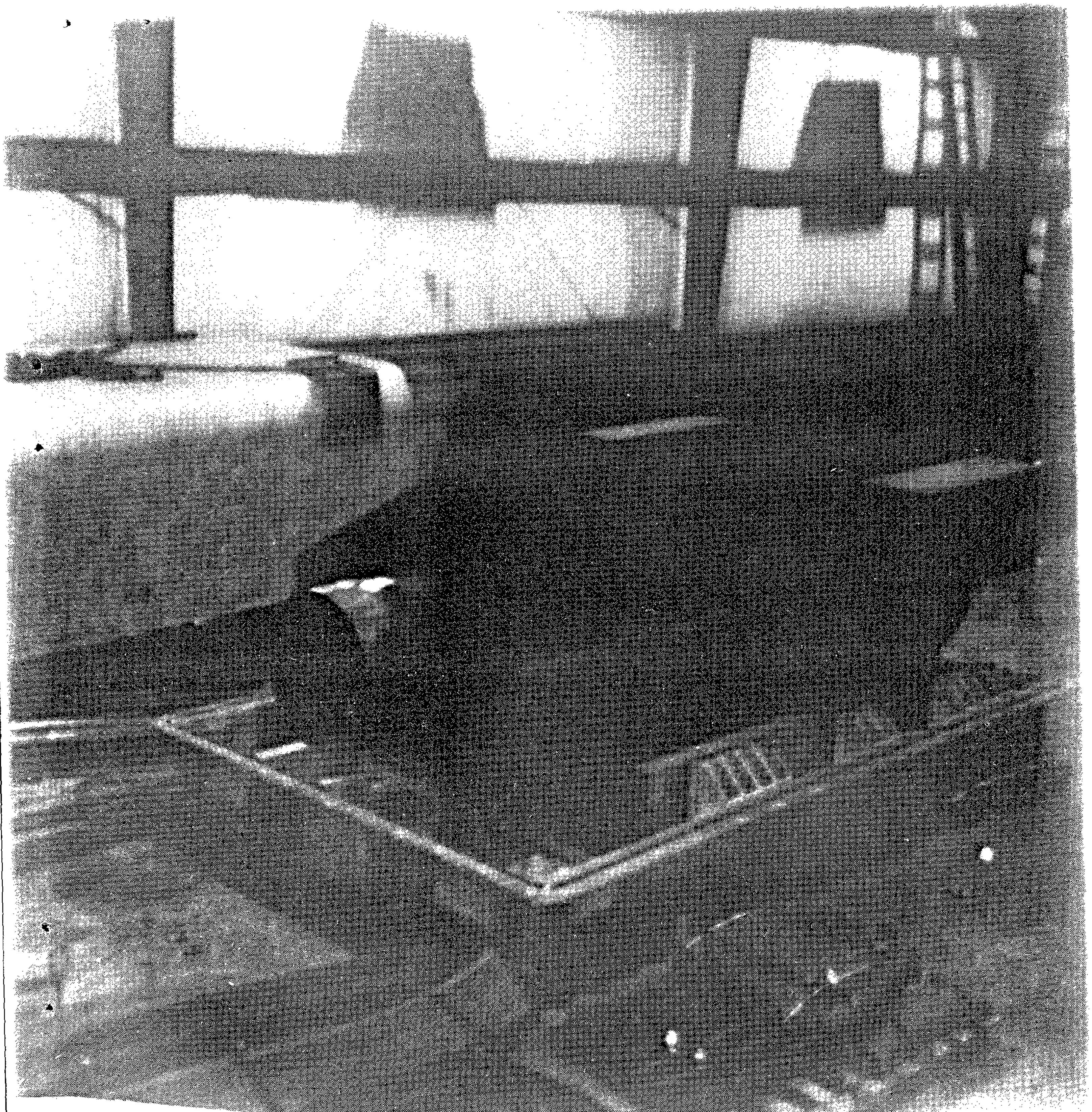
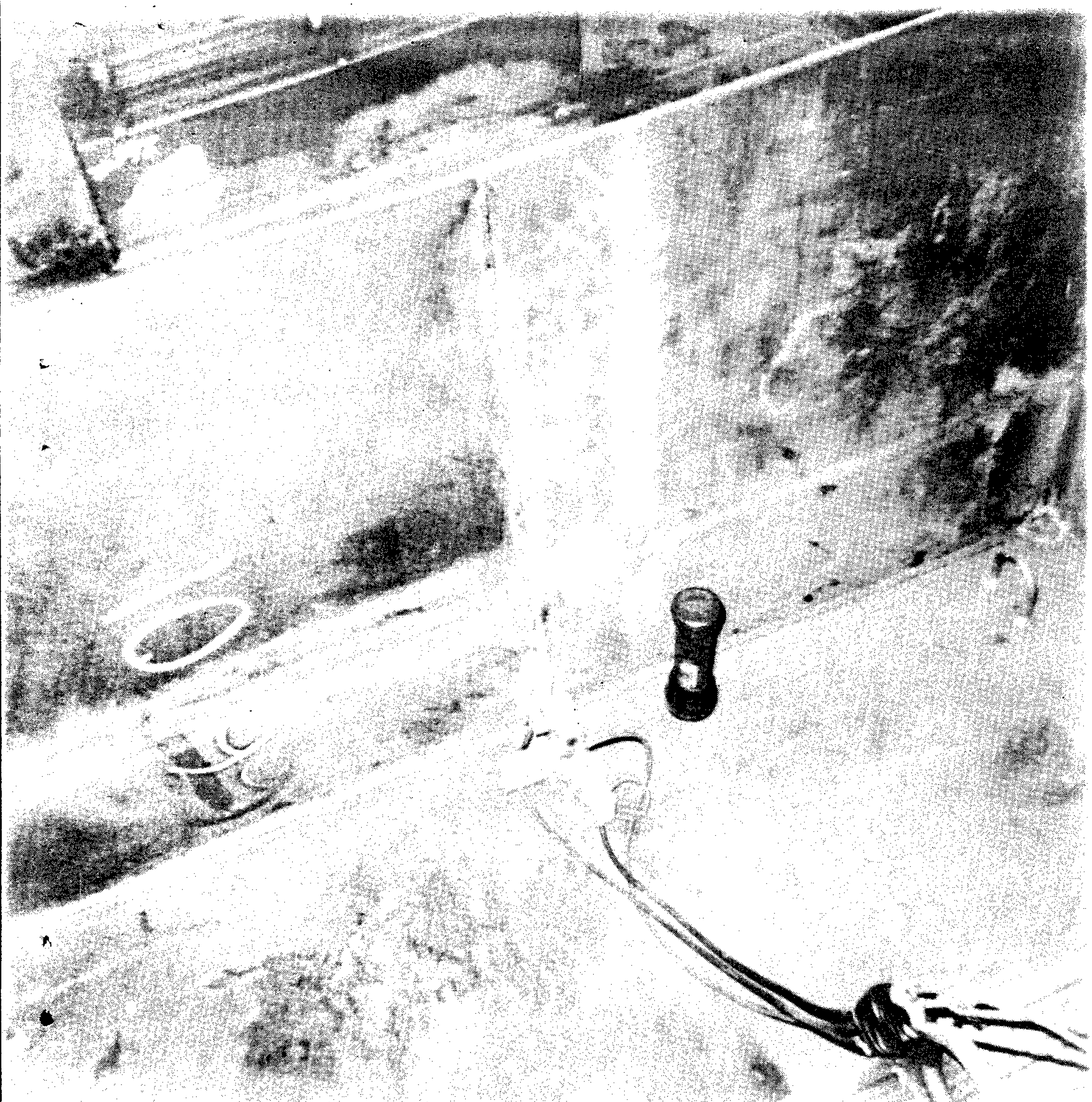
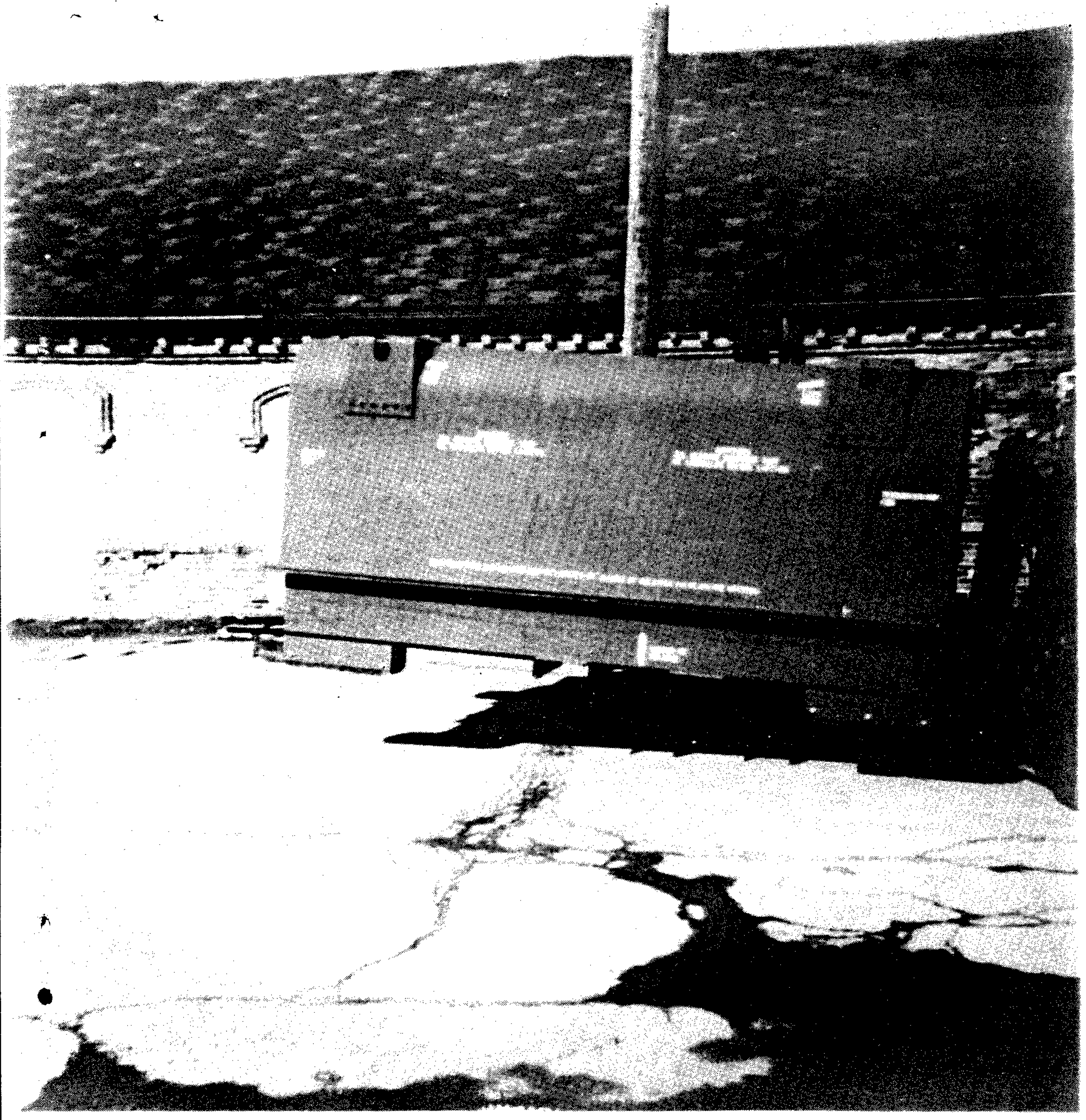


DUMMY LOAD INSTALLED

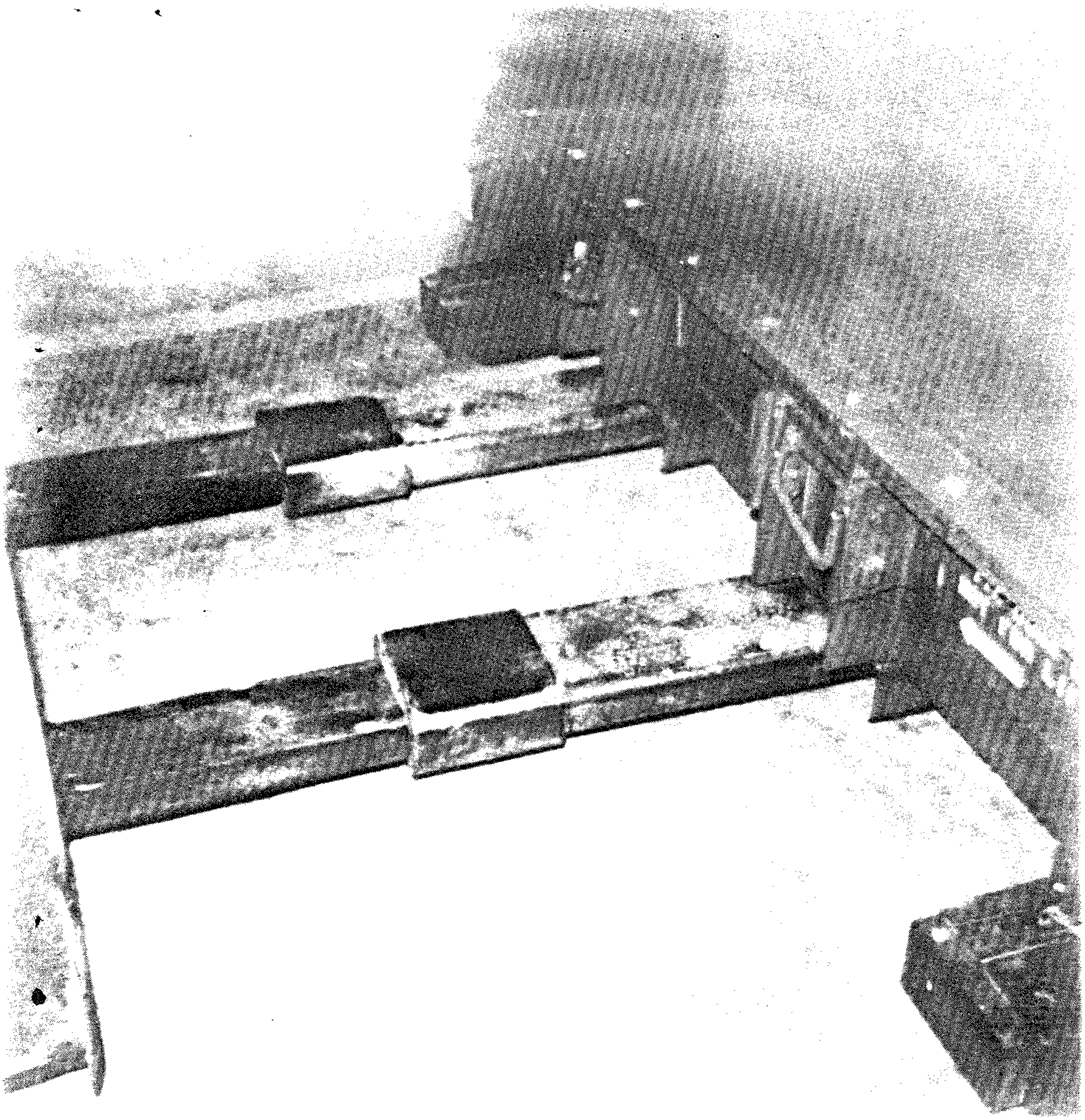


ACCELEROMETERS

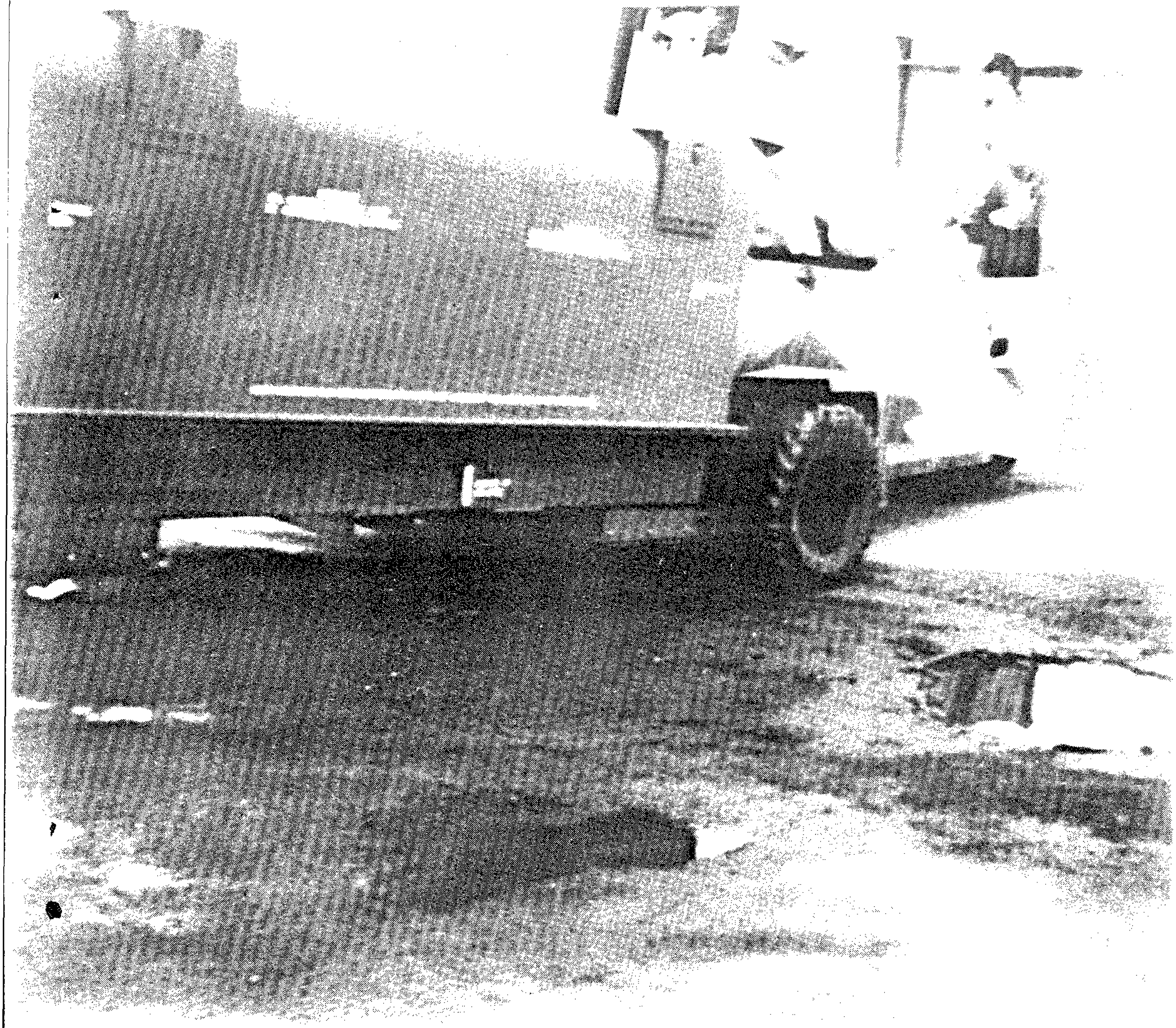
HOISING TEST



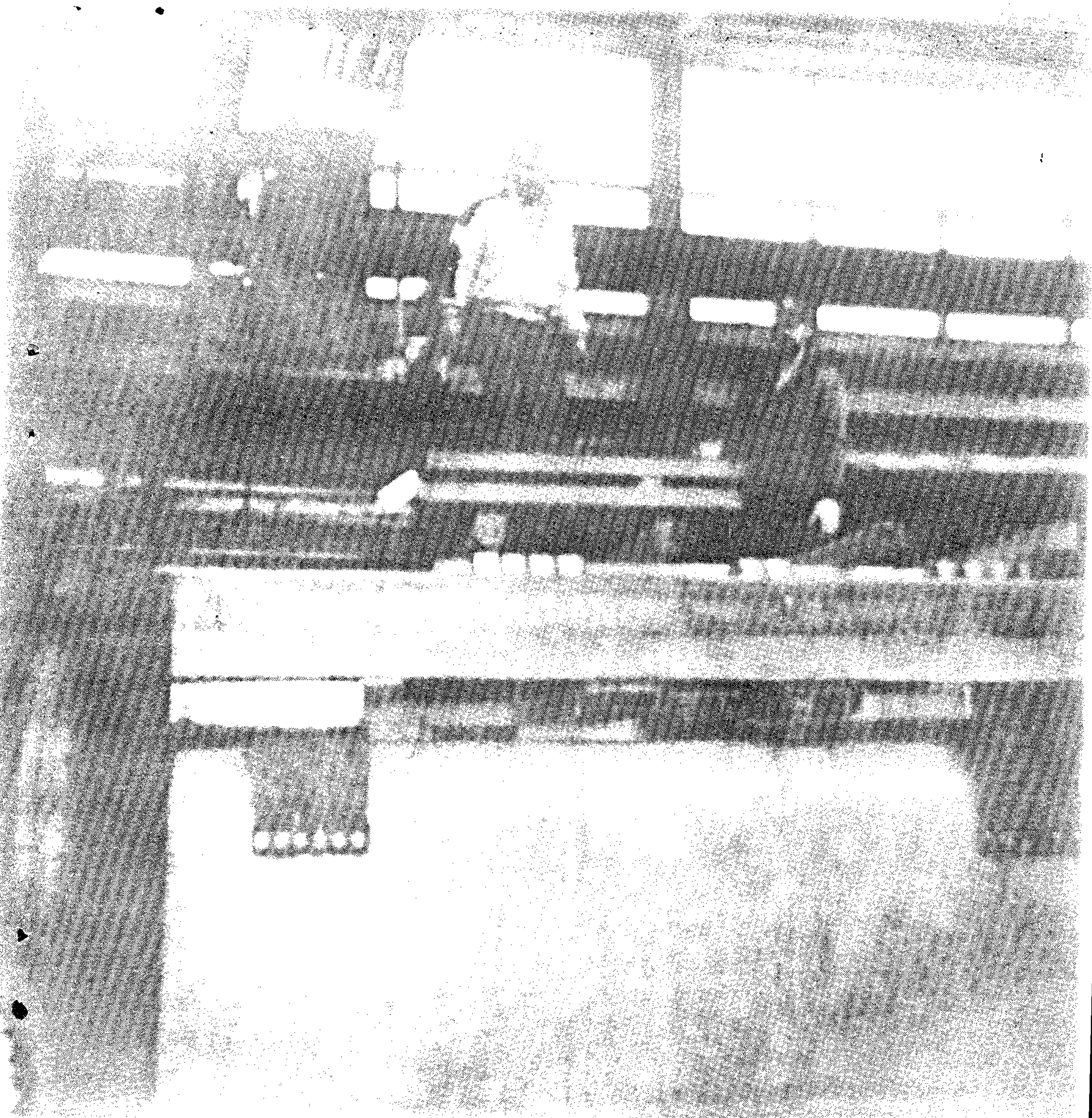
FORKLIFTING TEST (END LIFT)



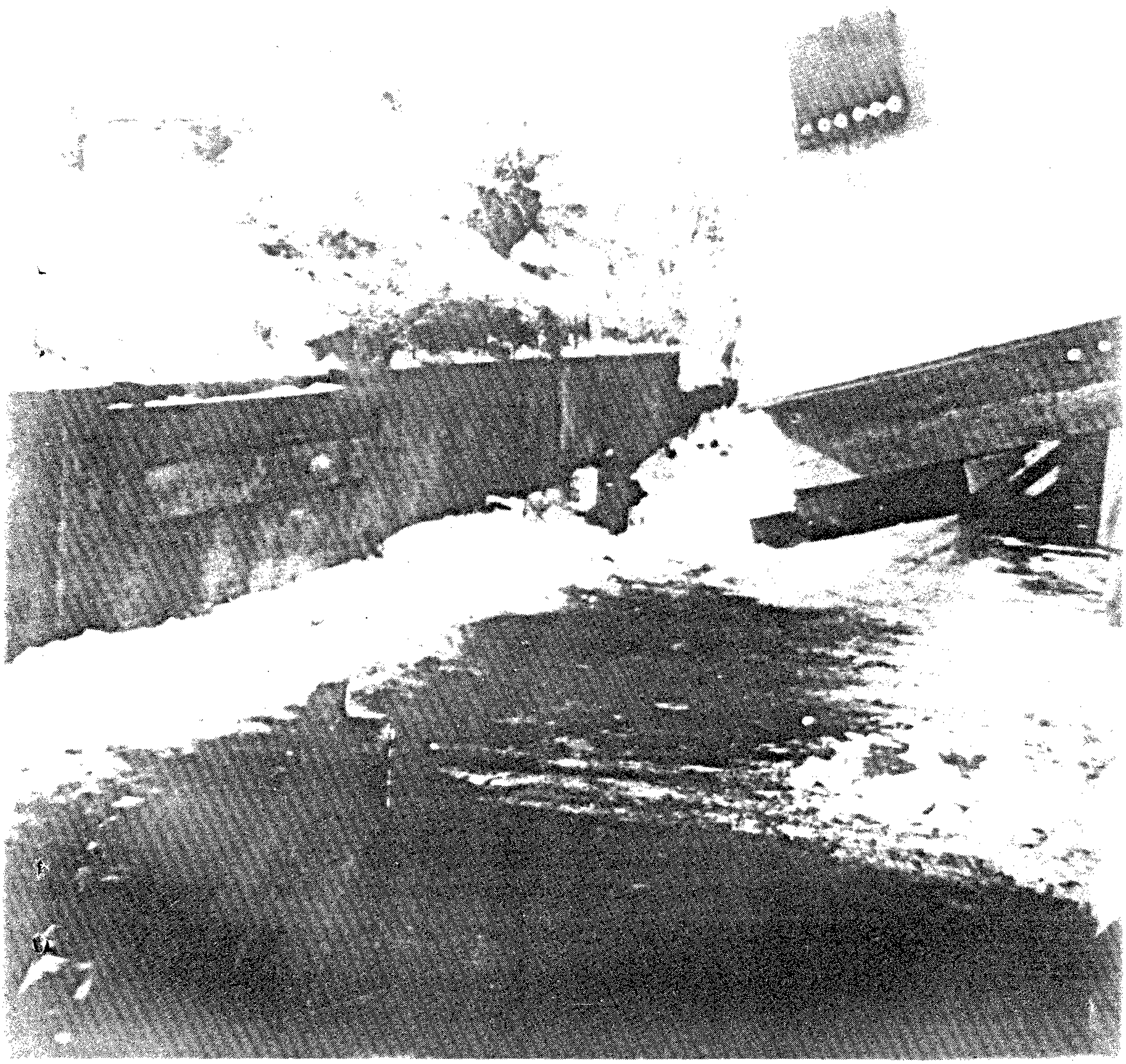
FORK TINE ENTRY



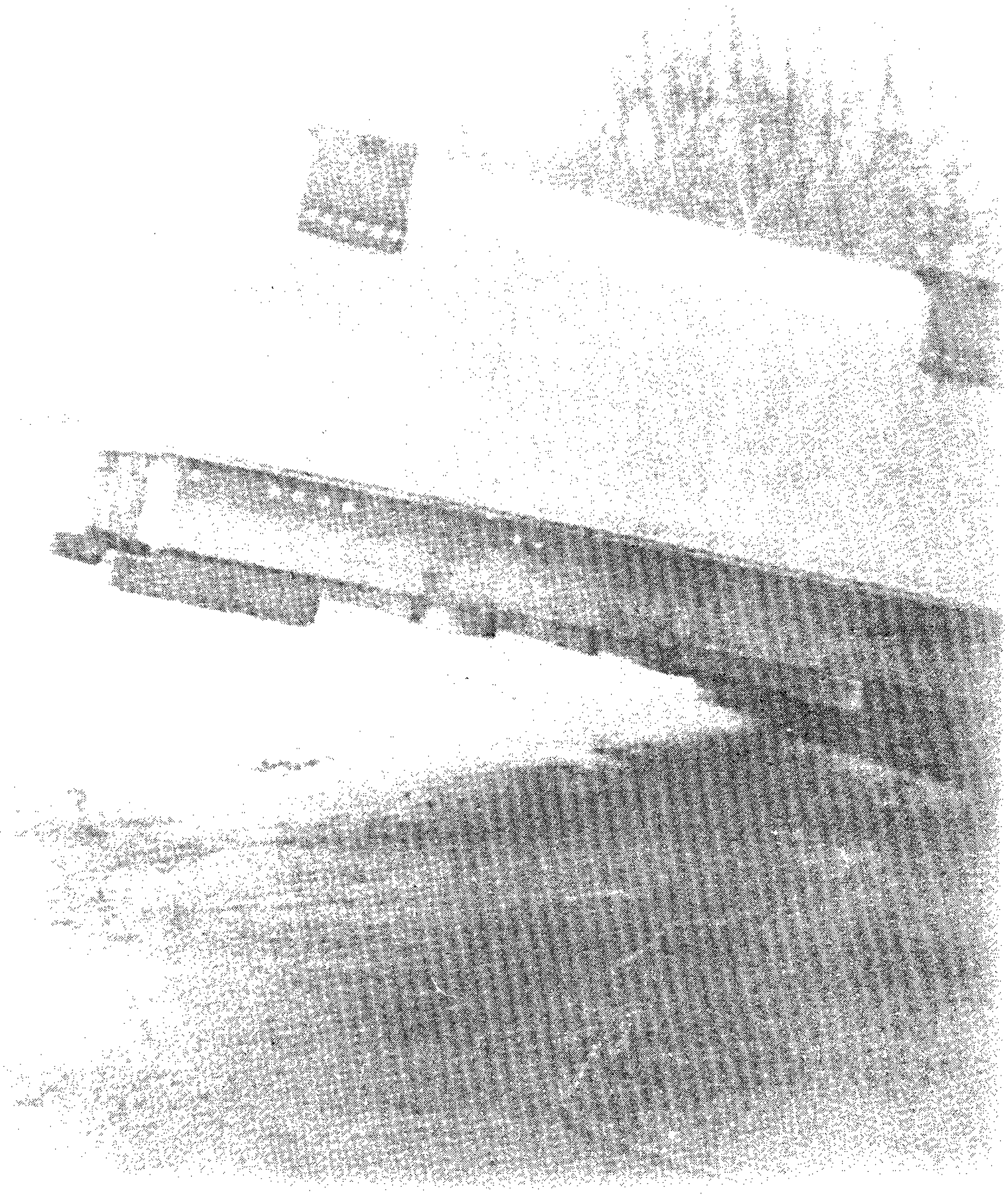
FORKLIFT TEST (END)



CONCENTRATED LOAD RESISTANCE

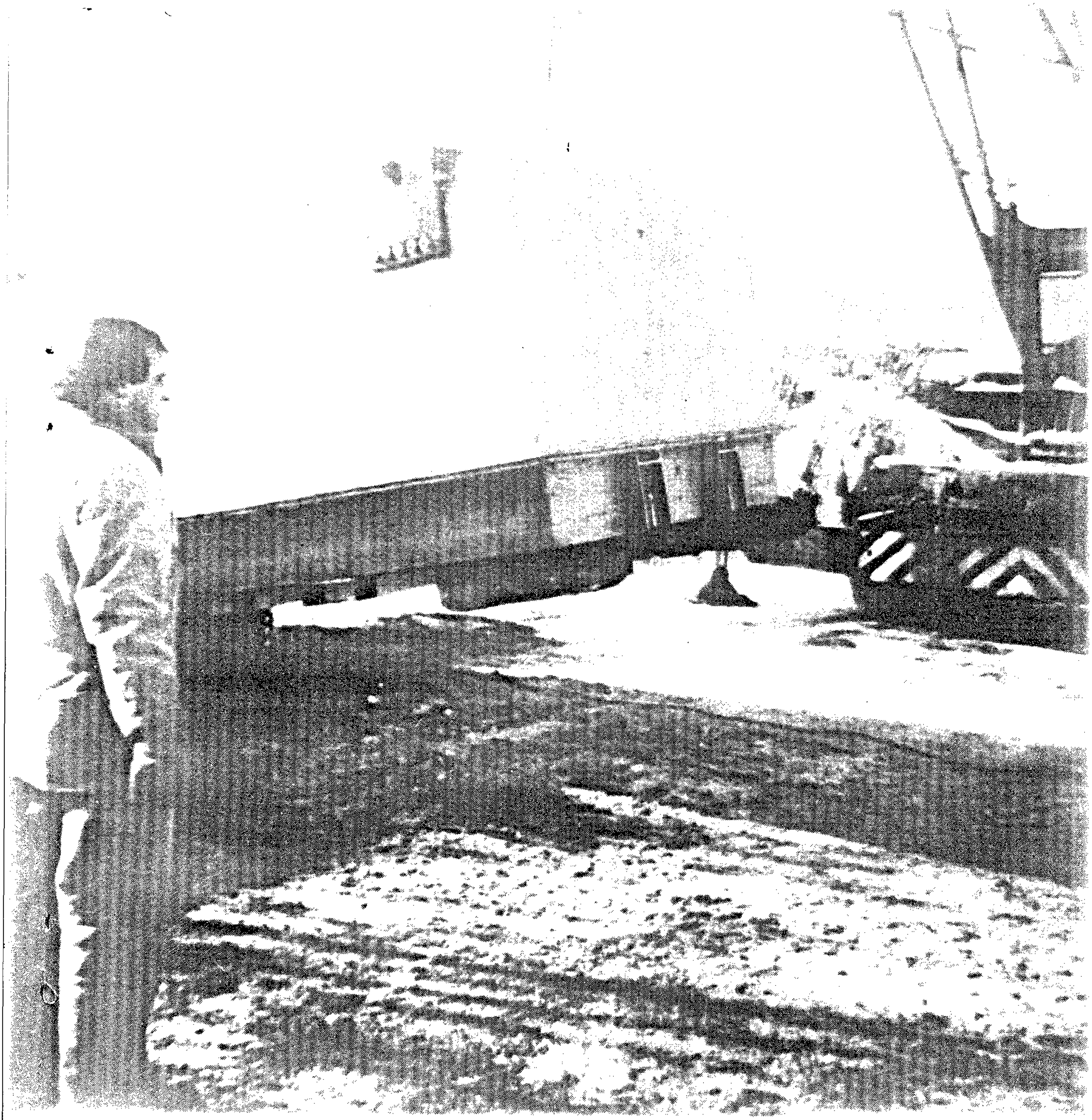


PENDULIM IMPACT (AFT END)

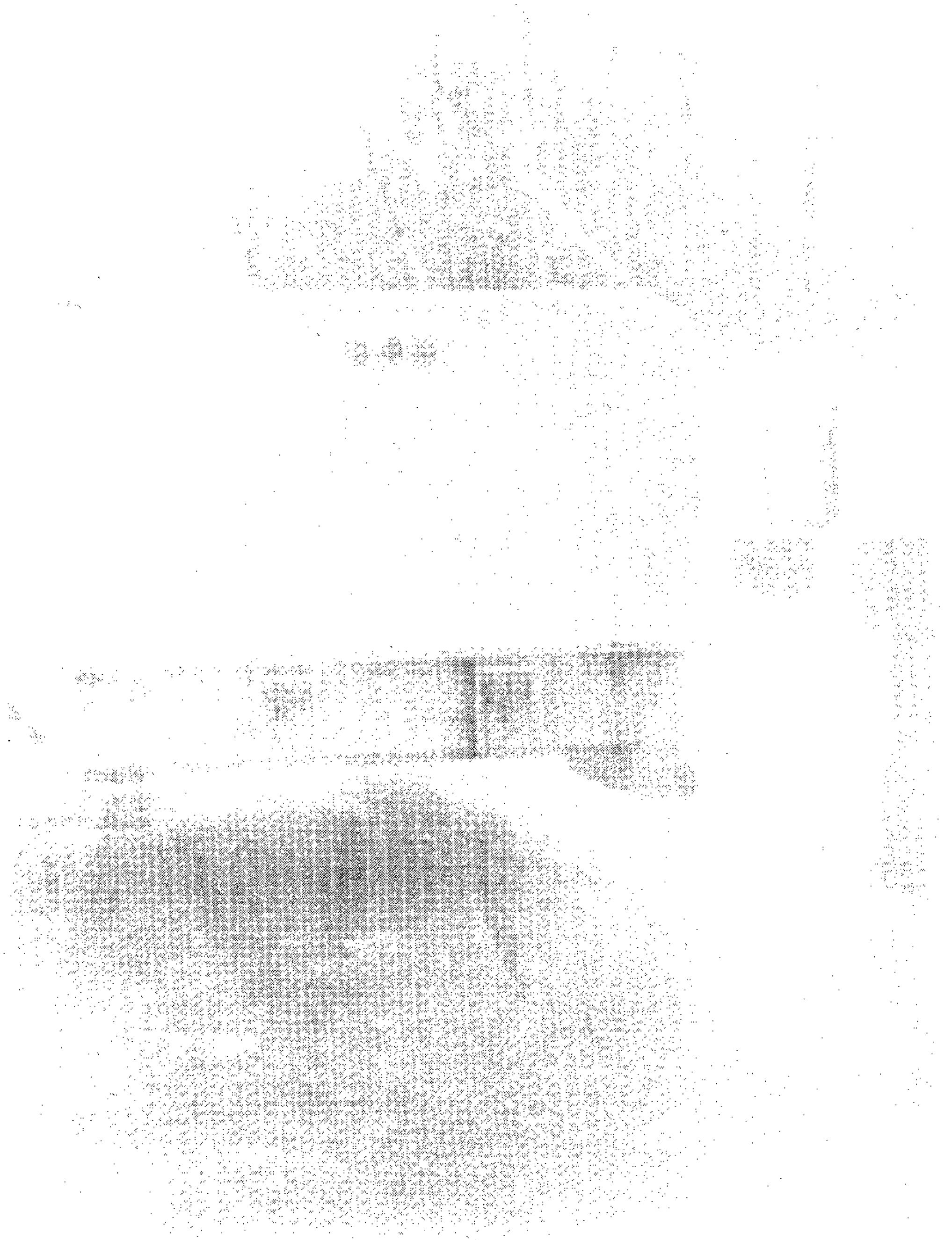


EDGEWISE DROP TEST (AFT END)

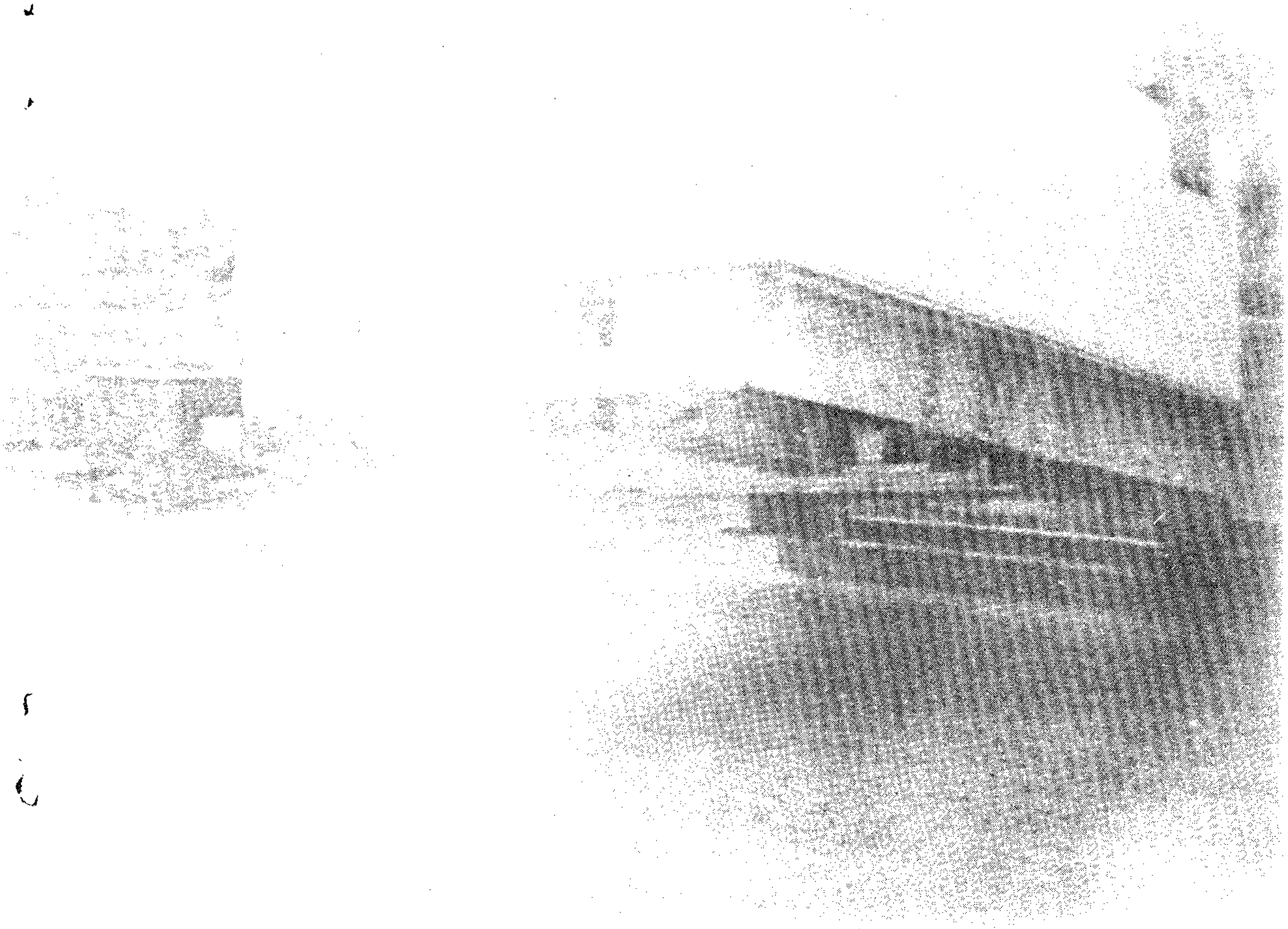
EDGEWISE DROP TEST (AFT END)



EDGEWISE DROP TEST
24 JAN., 90



FLATWISE DROP TEST
24 JAN.,90



CORNERWISE DROP (AFT CORNER)

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APPENDIX D

BALTEK CORPORATION
TEST DATA FILE 6

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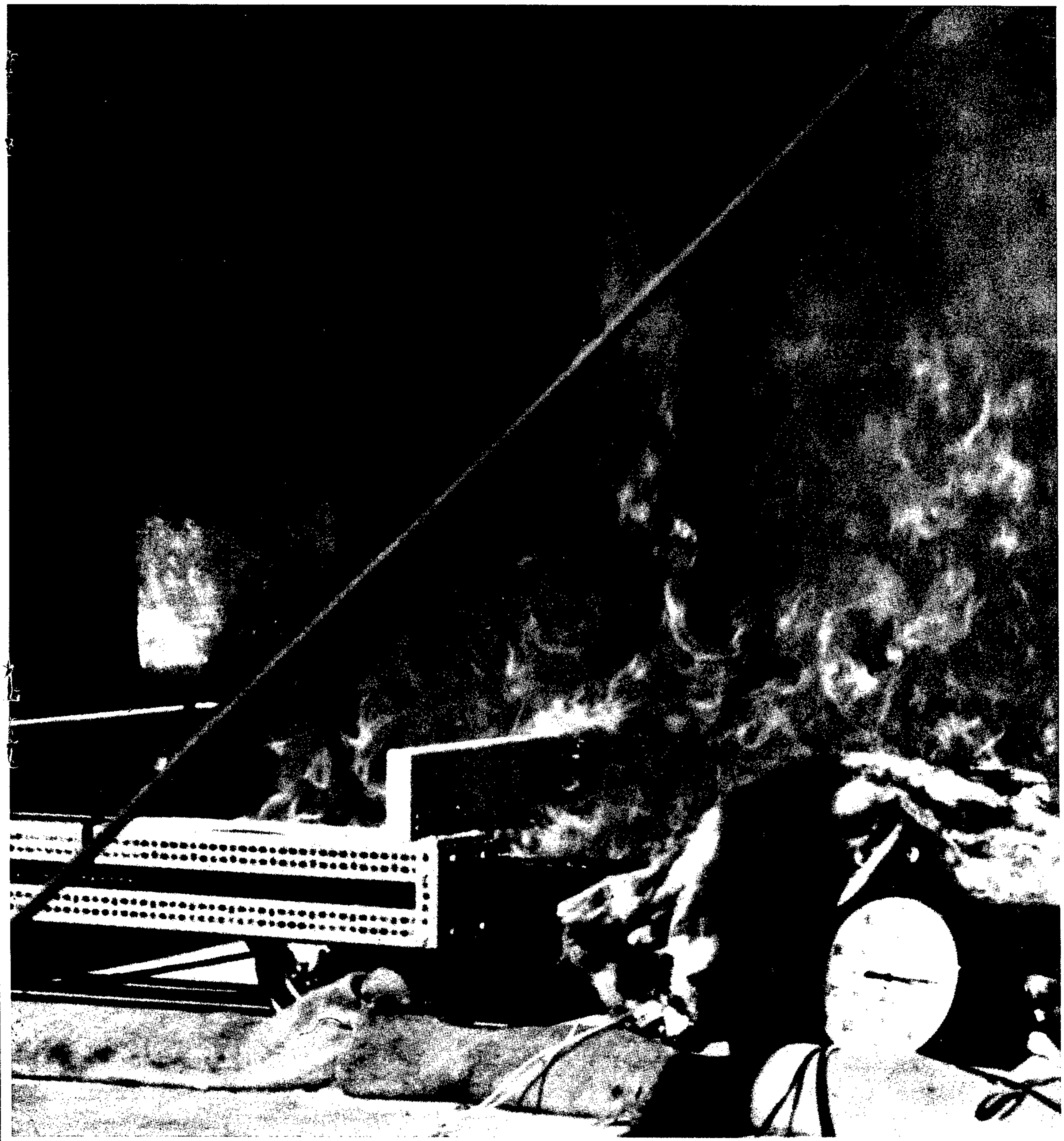
TEST DATA FILE 6

Dramatic Examples of the FIRE-RESISTANCE of CONTOURKORE®/FRP Construction



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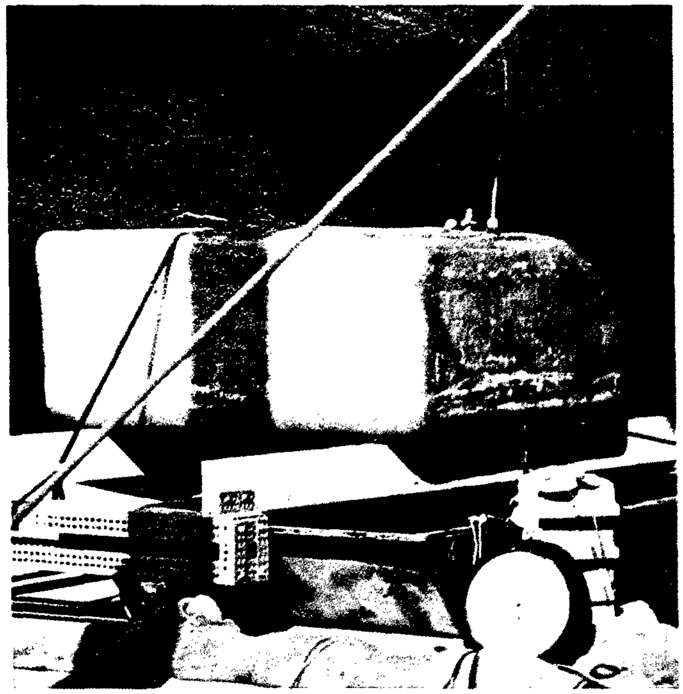
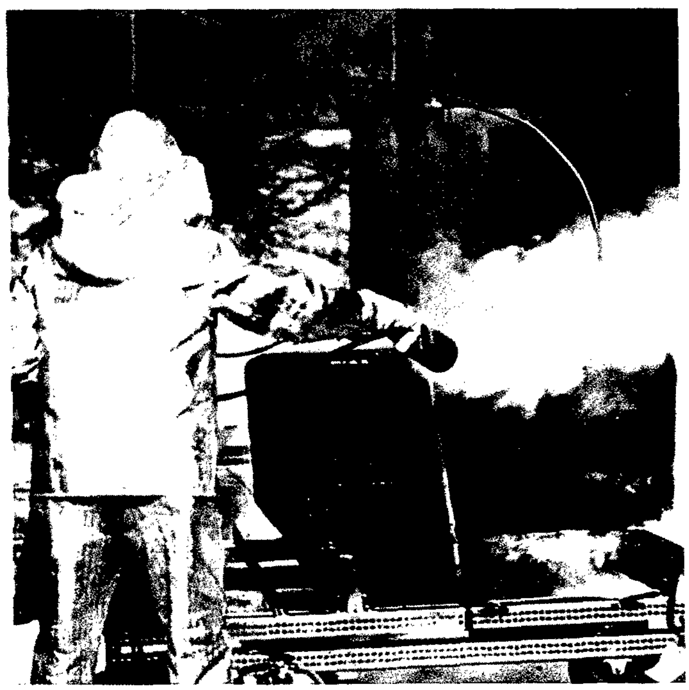
CONTOURKORE/FRP Fuel Tank Withstands Severe Fire Test Using Procedure Equivalent to Underwriters Laboratories Standard for Safety UL1102.

The original Concorde "Space-Capsule" fuel tank, constructed of fiberglass laminated with a core of end-grain balsa (CONTOURKORE) withstood a series of tests that, to that time, no other fuel tank had ever passed. These included a fire test so intense that the 20′ high roof of the test building itself was consumed ... yet the tank remained intact! In addition to the fire test, the tank had withstood a half-million internal strains, twenty-five thousand consecutive pressure pulses, and more than 250 10G impacts.

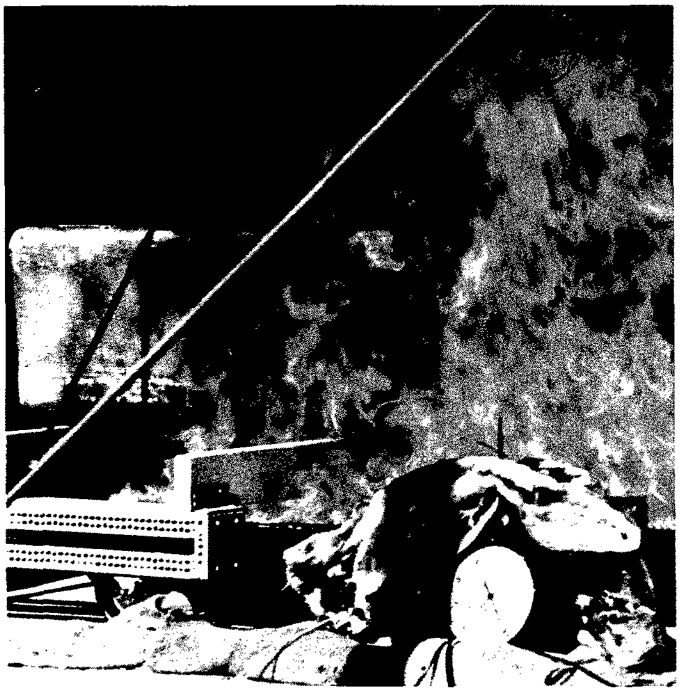
The fire test (photos of which are reproduced here) was made in accordance with the Yacht Safety Bureau Product Standards which are now included in Underwriters Laboratories Standard UL 1102. The results are dramatic proof of the durability, insulation, and fire-resistance of CONTOURKORE/FRP structures. Even steel tanks have failed to pass all the tests given the Concorde balsa/fiberglass fuel tank. Since then, this revolutionary method of fuel tank construction has been adopted by many builders.



1. The tank is mounted on steel beams, over two gasoline-charged pans. The tank itself is one-quarter full of gasoline. Thermocouples attached to the tank will measure the heat of the flames outside and gasoline inside. A clock records the elapsed time.

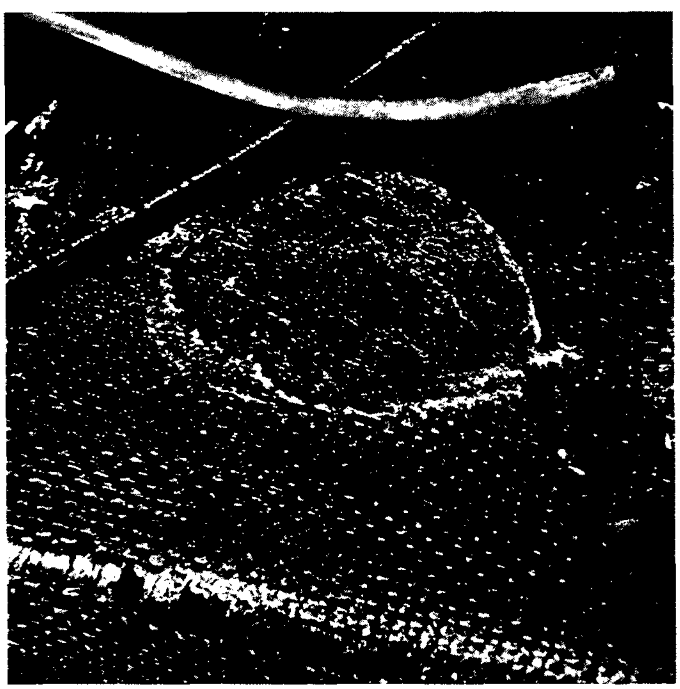


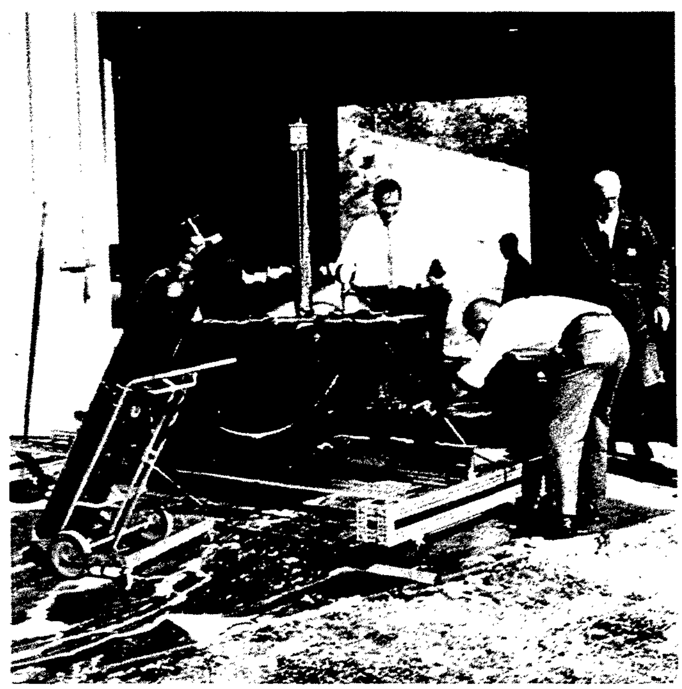
4. The tank was removed by cable. Small flames still clinging to surface were quenched within 30 seconds by self-extinguishing nature of the fiberglass resin. In photo, asbestos-clad technicians used CO_2 extinguisher as part of test procedure to assure termination of the test at the 2½ minute requirement (plus retrieval time).



2. Seven seconds after ignition. The flames rise at the forward side of the clock (shielded by fiberglass blanket on top). Rising heat sets up strong air flow increasing fire. Special fireproof shielding paint on test support beams begin to burn.

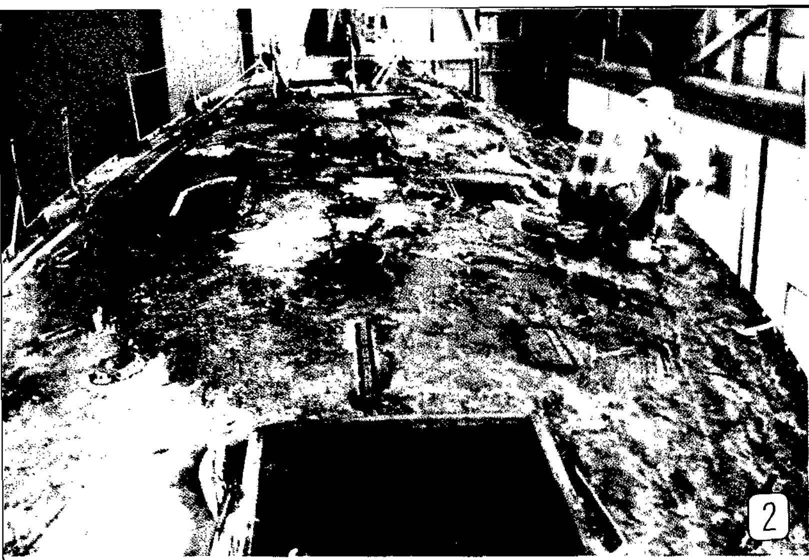
3. Full fury! Velocity of air causes flames to fill entire 20-ft. height of test building. Sandbags catch fire. At 2½ minutes, flames reach maximum intensity. Clock stopped at 2:10 because wiring was consumed. Even the fiberglass blanket is smoking.

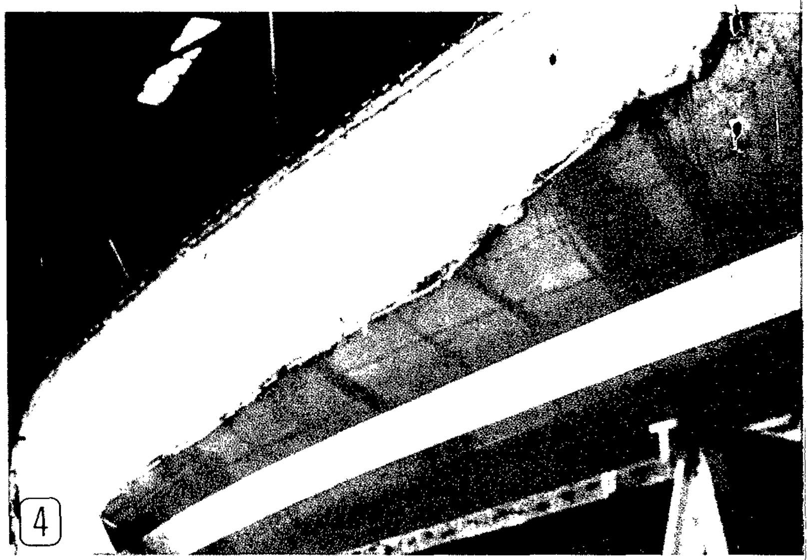




5. Only a small blister on outermost of tank's four ply skin showed any effect of fire. The inside three plies, when probed, were completely sound. Interior showed no signs of scorching or discoloration. Despite intense heat, temperature of gasoline inside the tank showed little rise.

6. Final test for hidden leaks. Technicians pump nitrogen under pressure into tank and spray water and soapsuds on exterior to detect any small leakage. The tank was so structurally sound that it was not only leaktight, but withstood full test pressure even without the outer ply of skin.





This 40-foot yacht was docked at a Long Island, N.Y. marina when an adjacent vessel caught fire and was destroyed. These photos show clearly how CONTOURKORE/FRP sandwich construction withstood the intense heat and flames, and prevented loss of the boat.

1. The intensity of the fire can be visualized by the twisted and melted metal deck fittings.

2. When the charred portion of the outer skin was cut away, the core of CONTOURKORE End-Grain Balsa was revealed to be the insulating agent which saved the vessel from total loss.

3. The close-up shows that the surface of the CONTOURKORE was charred but the charring did not penentrate into the core more than a fraction of an inch. It was evident that the CONTOURKORE did not support combustion.

4. Although the outer skin was completely burned away in large areas, the sandwich construction remained structurally sound enough to be repaired with relative ease.

CONTOURKORE®

Structural sandwich core material made of end-grain balsa attached to a flexible fiberglass scrim. CONTOURKORE is exclusively produced from BELCOBALSA® — balsa certified kiln-dried at the source. CONTOURKORE is covered by patents issued by the United States, Canada, England and France.

CONTOURKORE is internationally certified for hull and deck construction in fiberglass boats by Lloyd's Register of Shipping, Great Britain, the Registro Italiano Navale (RINA), Italy; Germanischer Lloyd, Germany; Det Norske Veritas, Norway; Bureau Veritas, France and Nippon Kaiji Kyokai, Japan. Equally significant, CONTOURKORE is the only major core material manufactured in the United States that has received a Quality Approval Certificate (NO. YSC/QA103) from Lloyd's Register. It is also approved by The White Fish Authority (including the Herring Industry Board), and has been a specified structural core material for U.S. Navy and Coast Guard craft for over two decades.

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